



Transport of Dangerous Goods through road tunnels: Quantitative Risk Assessment Model (v. 4.10)

User's Guide

Technical Committee D5 Road Tunnel Operations
World Road Association



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FOREWORD

The information provided in this report is intended to be used in whole or at least in an objective manner. The decision to only use excerpts of this information is done so under the full responsibility of the users. PIARC cannot be held liable for any modifications made to this report by outside parties or for the use of this report outside of its intended scope.

CREDITS

For a long time the joint Organisation for Economic Co-operation and Development (OECD) and the World Road Association (formerly known as PIARC) are developing strategy and objectives related to the transport of dangerous goods by road.

These works led to propositions which have been confirmed and integrated in the new directive (article 13) on Minimum requirements for tunnels in the Trans-European Road network. The main requirement is to perform a risk analysis before deciding on tunnel requirements with dangerous goods.

The present Quantitative Risk Assessment model has been developed since the beginning within the framework and objectives proposed by the OECD/PIARC and allows the QRA model to fit with the aims of the directive.

During the initial development process of the QRA model until version 3.61, INERIS (FR) has co-ordinated and proposed the technical solutions as well as participated to their implementations. This work has been carried out with the contribution of WS-Atkins (UK) and the Institute for Risk Research (CA).

CETU has coordinated the development of the QRA model. A Task Group within the World Road Association's Technical Committee D5 (TC D.5) on Road Tunnels Operations has also been involved, comprising members from working group 2 of the Committee. These members are DGQRAM experts and representatives of the countries funding the project. Version 4.10 of the software has been developed by BG Consulting Engineers with the contribution of ILF Consulting Engineers and ENALOS.

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WARNING DISCLAIMER ON INTENT AND USE

The algorithms, procedures and computer programs of DG-QRAM have been developed only for the assessment of risks related to the transportation of dangerous goods by road, along given routes and especially those with tunnels. They have been compiled based on the knowledge and understanding available at the initial development date (year 1998), but have important limitations that must be understood and considered by the user. The software package constitutes the QRA-model. For assessment of smoke propagation/ventilation, evacuation etc., there are other, more appropriate tools including 1D and 3D fluid dynamic models. Consequently, users are warned that whilst the QRA model may be used for dangerous goods risk assessment, it must not be the only tool used in the assessment of the acceptability of design proposals to achieve the required global tunnel safety levels.

PIARC makes no warranty, expressed or implied, to users of the QRA model and cannot be held liable for its use. Users assume sole responsibility for determining the appropriateness of its use in any particular application, for any conclusions drawn from the results of its use, and for any action taken or not taken as a result of analyses performed using this model. Users are warned that this model is intended for use only by those competent in the field of safety and the risk assessment of the transportation of dangerous goods by road, especially in tunnels. Moreover, users should undergo proper training prior to using the model. The QRA-model is intended as an aid in the decision-making process in this field, only to supplement the informed judgment of the qualified user. This model may or may not have predictive value when applied to a specific set of factual circumstances. Lack of accurate predictions by the model could lead to erroneous risk assessments with regard to the transport of dangerous goods through road tunnels. Therefore, all results should be evaluated by an informed user.

1. SUMMARY

The present document is a user's guide for version 4.10 of a software package initially written by INERIS (France) and WS Atkins (U.K.) (version 3.61). The Institute of Risk Research (IRR) from University of Waterloo (Ontario, Canada) also contributed to the initial version.

The initial work until version 3.61 had been performed under the supervision of a follow-up committee committed by OECD and PIARC and been funded partly by OECD and partly by the European Union.

A project entitled "DG QRAM upgrade" was launched because of the evolution of other software used with DG-QRAM (Windows, Excel, etc.), and because some countries wished to adapt the content. The project was split in two phases. The objective of the first phase was to update the tool in order to make it compatible with recent versions of software used with DGQRAM. The output of this first phase was the version 4.04. The objective of the second phase was to improve the tool. The output of this second phase is the version 4.10. A Task Group of the World Road Association's Technical Committee D.5 then C4 on Road Tunnels Operations was in charge of the project. CETU has coordinated this task group, assisted by BG Consulting Engineers (under the support of ILF Consulting Engineers for the second phase) and ENALOS. This project was funded by Austria, Belgium, Finland, France, Greece, Italy, Spain and Switzerland.

The objective of the software is to enable a user already aware of risk issues due to Dangerous Good transport to assess quantitatively these risks. The very basis of the method was already indicated in the Terms of Reference of the first call for tender in 1996.

It consists in the choice of a very limited number of scenarios involving a still more limited number of dangerous goods, evaluate simultaneously their consequences and probability of occurrence. This enables to assess quantitatively the societal risk (if a precise knowledge of the exposed population is at hand) and the individual risk.

In fact the developed tools may be used for different purposes:

- assess the societal risks due to dangerous goods transport for a tunnel or a route;
- compare the societal risk of a tunnel or along a route with reference criteria;
- assess the societal risks for each ADR category¹ (A to E) of a given tunnel in order to help choose one. The societal risk of category A and E correspond respectively to the societal risk of the tunnel route and of one (or several) alternative transport route(s).

The software produced is theoretically able to work for both purposes.

¹ "Accord for dangerous goods by **road**" : European Agreement concerning the International Carriage of Dangerous Goods by **Road** and absolute use for comparison of the risk with "acceptance criteria".

This Quantitative Risk Assessment Model (QRAM) was build very flexible so as to be able to deal with complex situations (for instance routes that differ as a function of time periods and/or direction). As a corollary, the resulting software itself is very complex and needs a substantial amount of data.

So, from the first beta version of the software, strong guidance have been provided to the user by means of dialogue boxes. The aim for that was to forbid inputs of conflicting, erroneous or incomplete data.

The user enters these data through dialogue boxes, when creating a new case from scratch. For existing cases he has the possibility to edit the existing data file, and perform on it non structural modifications (the number of sections cannot be modified but the traffic and other characteristics are at user's hands).

The tool enables to calculate risks regarding injuries as well as fatalities, local population or road users only.

The QRAM runs in an Excel environment, with help of VBA (Visual Basic Application) libraries. The user has to pay a strong attention to the Windows and Excel required settings, and the Excel installation, that must be complete. It is strongly recommended that the risk assessment tool user has a solid knowledge of personal computers.

In Annex 6 guidance is given for the installation and tests that may be performed to check it has been correctly done.

2. GLOSSARY

2D:	Two dimensional
CCTV:	Close Circuit Television
CD-R:	Readable Compact Disk
DG:	Dangerous Goods
DG-HGV:	Heavy Good Vehicle that transports Dangerous Goods
EU:	European Union
EV:	Expected value (global indicator of societal risk)
HGV:	Heavy Goods Vehicle
IRR:	Institute of Risk Research from University of Waterloo (Canada)
local population:	by opposition to Road Users we consider as local population all the people who are not road users aboard their vehicles or disembarked because escaping. In a tourist resort, tourists are considered as local population.
Mb:	megabyte
MTMD:	Mission Transport des Matières Dangereuses; Division of the French Ministry of Transport that (among other things) publishes and regularly updates a database of accidents having involved transports of dangerous goods.
OECD:	Organisation for Economic Co-operation and Development
PIARC:	World Road Association
Pre-Conditioner:	Module of the software package specifically in charge of the tunnels
QRA(M):	Quantitative Risk Assessment (Model)
Risk-DG:	2D module of the software package
Rk-DG:	Shortening for Risk-DG
Road Users:	The people aboard a vehicle or who have left it to escape a danger.
Section:	For Sk-DG and Rk-DG, it is a part of the route which is considered as homogeneous for both directions (separately if route description is operated separately for the 2 directions). A tunnel is a section and just a section. For the Pre-Conditioner, it is a longitudinal segment which represents only a part of a tunnel.
Sk-DG:	Leading module of the software package
VBA (5):	Visual Basic for Applications (version 5)

3. COLOUR CODING

The QRA model is divided into 3 parts.

The central one, that contains the core coding of the QRA model, is not directly accessible to the user that runs a calculation.

The user faces the two remaining parts:

- The input data file,
- The result files.

In those two types of files, the colour coding is the following:

- Normal titles or comments appear in green letters on a pale blue or a pale yellow background.
- Important notes or error messages appear in bold red letters.
- All the variables used by the QRA model appear in black letters. Those which are on a pale blue background can be modified by the user. Those which are on a pale yellow background result from formulas and should not be modified by the user (they are normally write protected to avoid errors).

4. INTRODUCTION

This guide is relative to version 4.10 of the QRAM.

Ms-Excel systematically used the file extension “.xls” prior Ms-Excel 2007 (version 361 of the QRAM). For version 4.04 and later the extension is “.xlsm” [not “.xlsx” because the involved files contain macro-commands]. In this guide we will note the new extension “.xls(m)” in order to emphasize the change.

The objective of the software is to enable a user already aware of risk issues due to Dangerous Good transport to assess quantitatively these risks. The very basis of the method was already indicated in the Terms of Reference of the 1996 call for tender.

It consists in the choice of a very limited number (initially 10 and then 13 since version 3.60) of scenarios involving a still more limited number of dangerous goods, evaluate simultaneously their consequences and probability of occurrence. This enables to assess quantitatively the societal risk (if a precise knowledge of the exposed population is at hand) and the individual risk.

In fact the developed tools may be used for different purposes:

- assess the societal risks due to dangerous goods transport for a tunnel (or a route including a tunnel) according to each ADR category (A to E) or an open air route ;
- assess the whole societal risks (or the "global" risks) of the tunnel route and the alternative route. Indeed, when there is a route with a tunnel and an alternative route, the choice of a non permissive ADR category (B to E)² for the tunnel decreases the risk due to the DG traffic for the tunnel route, but, increases it on the alternative route where DG traffic that are not allowed on the tunnel route would pass. The QRAM, with a specific tool described in Appendix 9, makes it possible to assess this global risk due to the DG traffic on both routes.

² the ADR category A corresponds to the case where all DG (Dangerous Goods) transports are allowed in the tunnel

In practice, it should be kept in mind that this kind of risk assessment is something terribly complex and a lot of assumptions and/or simplifications have to be used at different stages.

They bring a certain level of uncertainty to the final assessment. Concerning the frequency aspect, IRR found uncertainties ranging from 250 % to 400 % with a 95 % confidence interval (concerning the consequence aspects, the uncertainties are of the same order of magnitude). A sensitivity analysis showed how the model reacts to key parameters variations.

This point illustrates why it is preferable to use the tools for comparison purposes. However, it is not necessary to consider two different routes to perform a comparison. For example, to consider the same tunnel route with different levels of equipment and/or with different strategies for DG transport fits with the comparative use.

Concerning the use for an absolute assessment of risk levels due to the transport of thousands of different dangerous goods, the method based on a conceptual simplification of the awfully complex reality is undoubtedly bearing an additional conceptual error.

It should be stressed that the risks which are assessed are the ones due to Dangerous Goods directly. Risks due to traffic accidents of DG HGVs that would not imply directly the Dangerous Good are not taken into account.

5. INSTALLING AND RUNNING THE PROGRAMS

5.1 HARDWARE AND SOFTWARE REQUIREMENTS

The QRAM software is encapsulated in a Windows executable installation file (format “.exe”). The person launching this executable installer should have administrator’s privileges. If not, installation will not succeed or remain incomplete.

In 1996, the computer and graphic display had to meet certain requirements in order to enable QRAM computations. Today all computers equipped with one of the systems and one of the versions of Ms-Office listed in § 1 of Annex 6 will do.

A lot of different combinations are possible. Moreover, each of these Microsoft products may be parametrised in many different ways. So, it is very difficult to predict the way the system will behave and the messages it will issue. There might be differences between those you get and the ones you will find in this manual.

It is important to note that Microsoft Excel has to be installed with its full VBA capabilities. The macro-commands included in the software package are using a wide range of VBA instructions that will cause failure at each run of the QRA model if VBA is not fully operational.

5.2 INSTALLATION AND SETTINGS

5.2.1 INSTALLATION

Installation is automatically performed by the “.exe” installation file.

It is done in 2 steps:

- 1) install the software in a target directory which will be called “installation directory” in the rest of this guide
- 2) install c:\functions.xla as a potential complementary add-in for Excel

Follow the steps detailed in Annex 7.

5.2.2 MS-WINDOWS SETTINGS

The QRAM will not work correctly if the operating system is not tuned adequately.

The QRAM needs a British/UK environment to be used.

With this setting, the default decimal separator is a dot symbol (.) – not a comma (,) like for many European users.

This setting is performed in the “Regional Settings” item of the control panel.

With elaborate versions of Ms-Windows, the regional settings may be customized differently from one account to another. So, if your version is an elaborate one, it is possible to have an account with UK settings dedicated to the QRAM and other accounts keeping other country settings. The regional setting may be tested using file `liste_prevert.csv` (see Annex 6).

5.2.3 MS-OFFICE AND MS-EXCEL SETTINGS

The QRAM will not work correctly if Ms-Office and Ms-Excel are not tuned adequately. Ms-Office is tuned adequately

- if Ms-Excel settings comply with those detailed in the PDF files named “`Excel-20xx_Tuning_EN.pdf`” where `xx` is 07, 10, 13, 16 accordingly to the Ms-Office release
- and if VBA is fully installed.

5.2.4 FUNCTIONS.XLA

The software uses a certain number of additional private functions (and subroutines) which are stored in file “`Functions.xla`”. This file must imperatively be present in the root `C:\` (partition where Ms-Windows system is present).

At the end of an installation, check the presence of file `c:\Functions.xla` (it may keep a Read/Only status).

If no version of the QRAM has ever been installed on the computer, to make things work properly, an initial declaration of these additional functions as Ms-Excel “add-in” is needed.

The general procedure (shown in annex 6) may be resumed as follows:

- open Ms-Excel,
- select menu and sub menus “`Tools`”; “`Add_ins...`”; “`Browse`”
- select file `C:\Functions.xla` and click OK,
- close Ms-Excel,
- reopen Ms-Excel.

If you want to check that the installation has been properly done, simply use the file “`Test_functions_as_addin`” located in directory “`installation_test`” (just click on it in your file manager).

5.2.5 ADDITIONAL REMARKS

Versions 3.60 and 3.61 of the QRAM used to launch 2D computations through a specific “Rk.pif” file which had to be located at a specific well defined location. This brought limitations. In the initial versions of the QRAM, the only possible installation directory was: c:\qram_dg.xxx With version 3.61, a degree of liberty existed the installation directory could be u:\qram_dg.361 where u was any letter in the range [c:z].

Versions 4.04 and later no longer uses “Rk.pif” files. The previous limitation has completely disappeared and the QRAM may be installed anywhere.

The Table 5-1 below lists the main installation changes for the versions of the software.

Versions	Type of file used to initiate the DOS instances	Installation procedure	Target directory	Excel compatibility
3.61 and earlier	Rk.pif	Decompression of a zip file to a target directory (limited choice). Copy of the non editable relevant Rk.pif in the right directory	Root of a partition chosen between less than 26 possibilities	1997, 2000, 2003
4.04 and later	Rk.exe direct launch	Modern commonly used installation procedure to a target directory (unlimited choice).	Chosen freely	2007, 2010, 2013, 2016 32 et 64 bits

Table 5-1: Main installation changes for the different versions of the software

In order to work, the software needs the installation of a working main directory and a certain number of subdirectories forming a tree (see Figure 5-1). This is performed automatically during the installation procedure.

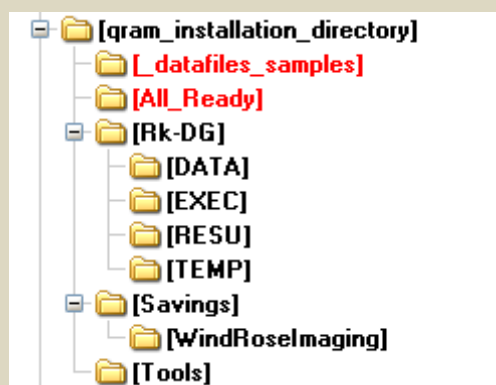


Figure 5-1 Tree of the subdirectories

Subdirectories can be added to the tree (those in red letters), but the ones listed in black letters in Figure 5-1 must be present and their names cannot be changed. All these directories contain specific files. At the beginning of each computation, the presence of the needed files is checked. Deleting such a file, renaming it or renaming the subdirectory will stop the computation and display a warning message.

5.2.6 PRINTER

- **Note for printers:**

To use the QRAM software, you must have a printer installed. This is because, the software has graphic outputs (see § 7.2.1 page 68) and their correct setting in a page requires the declaration of a default printer, whether you intend to print or not the graphical outputs. If you have no physical printer, simply install a virtual one (printing in a file).

5.3 REPORTED PROBLEMS

Windows related problems

- **Dots/commas problems.**

The modification of regional settings in the control panel allows the QRA to work without unexpected endings. However, in spite of this modification, one can observe in some occasions in some dialogue boxes random appearances of commas instead of dots as decimal separator. This trouble seems to be due to the fact that modifying the Windows regional settings does not modify all formats of numbers (for instance, it seems impossible in certain cases to put a dot to negative number format as decimal separator).

To solve the problem, the user should just put a dot where a comma appears in the related dialogue box, and the program will go on normally.

- **Excel related problems:**

After having entered a case for the first time, the QRA generates a data file. This file can be re-used as much as the user likes to compute modified cases (see § 6.3). The modification of a lot of cells is guided by dropdown boxes/validation notes. The developers have encountered, in some occasions, unexpected endings of the macro after having selected a “dropdown” cell and then run a macro.

So it is recommended that the user selects a cell that contains no dropdown/validation possibility before running a macro.

- **Lazy keyboard**

When entering a new case, the user is always guided from the first data entry to the results display. This is achieved by a macrocommand that runs in the background without interruption. This background activity interferes with a correct

handling by the system of the interruptions generated by the keyboard. This is sometimes irritating for the users who do not understand why the letters or numbers they are typing are not displayed on the screen. Be patient and insist. They will appear. Pay a constant attention to the data entered in those occasions. This concerns mainly the description of the tunnel sections (pre-conditioner) and the 2D population grids.

- **“No media present” interruptions**

A majority of the files located in the installation directory and its subdirectories are modified during execution, but not saved if the execution works normally (this does not concern data files which are systematically saved after the execution). So, the next execution finds them in their original state. But, these files supposed to remain unchanged may be saved or recovered by the system if the execution fails. If so, next execution may use altered versions of these files which may lead to problems. If you encounter difficulties and suspect that some of the files (not the data files) have been changed, it is better to make a new fresh installation in another directory. The data files may then be copied between “Savings” subdirectories.

DOS related considerations

The 2D calculations are performed in a DOS Command window that will be automatically opened by the software itself.

During the execution of the 2D calculations, messages are displayed in the DOS Command window. If execution is normally completed, the user has no reason to pay attention to the displayed messages. They become useful if execution is stopped for a reason or another (Access denied to a file for example, indication that the effects may overlap the grid borders).

5.4 UNDERSTANDING TOOLS IMBRICATION

The package contains mainly 3 software tools, namely:

- Sk-DG
- the tunnel Pre-Conditioner,
- Risk-DG.

The tunnel Pre-Conditioner and Sk-DG are spreadsheet tools composed by:

- sheets either filled with formulae, and/or data, and/or results,
- macro-commands.

Risk-DG is a software written in Fortran programming language. It is run in a DOS Command Window. But the user does not have to bother with this because all this is done automatically by macro-commands of Sk-DG.

Figure 5-2 shows the role of Sk-DG and the exchanges (input/output) with the two other modules: the Pre-Conditioner and Risk-DG as it was in version 3.61 and earlier versions. On this figure, the chronological steps are pointed out. You do not have to pay attention to the names in red letters. They refer to the subroutines of Sk-DG and this kind of information is only useful for experts.

With version 3.61, Ms-Excel was left in a waiting state while the 2D computations were performed.

Modern processors have several cores and can run several applications at the same time. Therefore, the general algorithm has been rewritten to make Excel calculate the tunnel and 1D sections while in the mean time 2D Fortran computations are performed in DOS boxes (see Figure 5-3).

VERSION 3.61

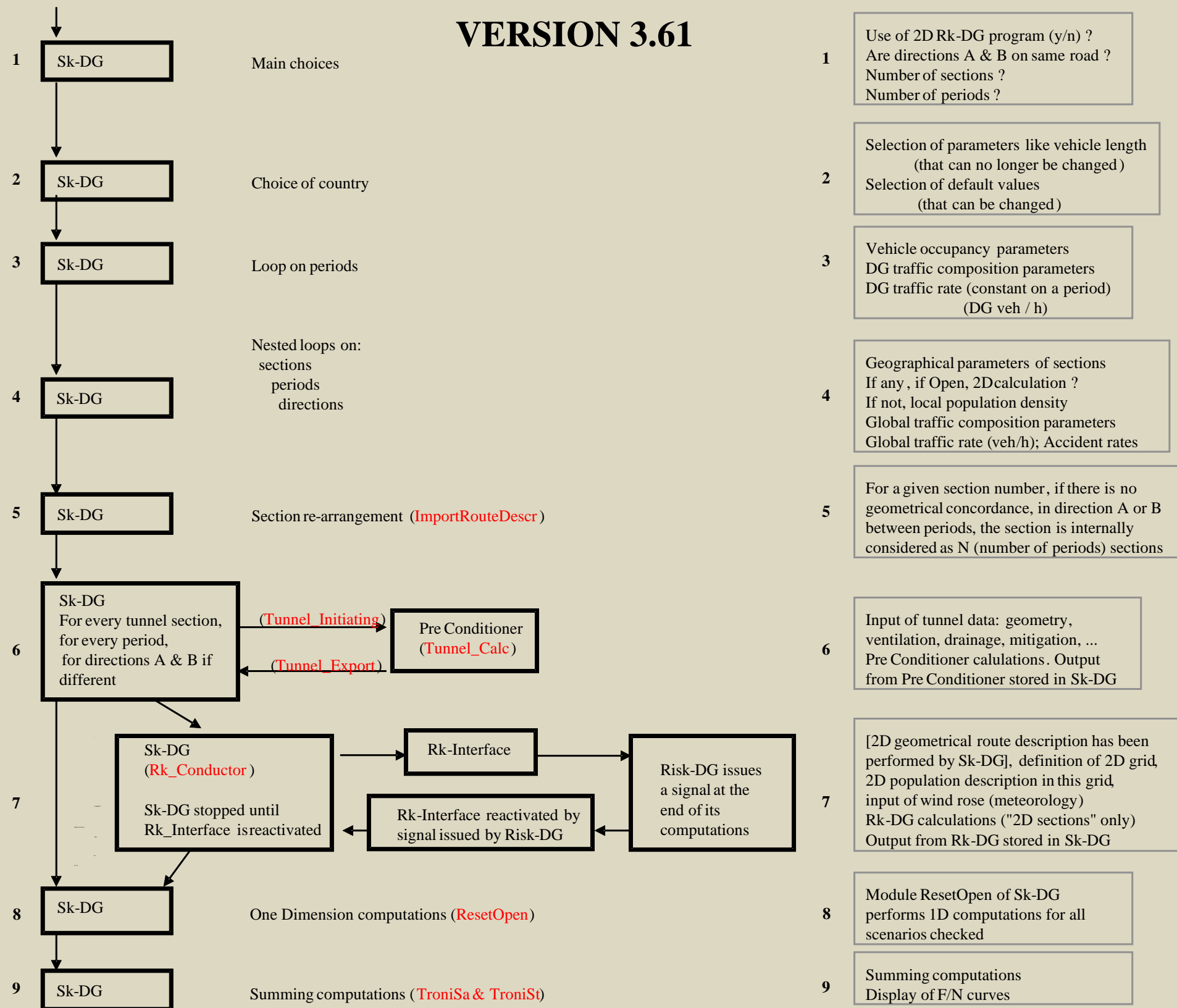


Figure 5-2: Role of Sk-DG and exchanges (input/output) with the two other modules: the Pre-Conditioner and Risk-DG (Version 3.61 and earlier versions)

VERSION 4.04 (and later)

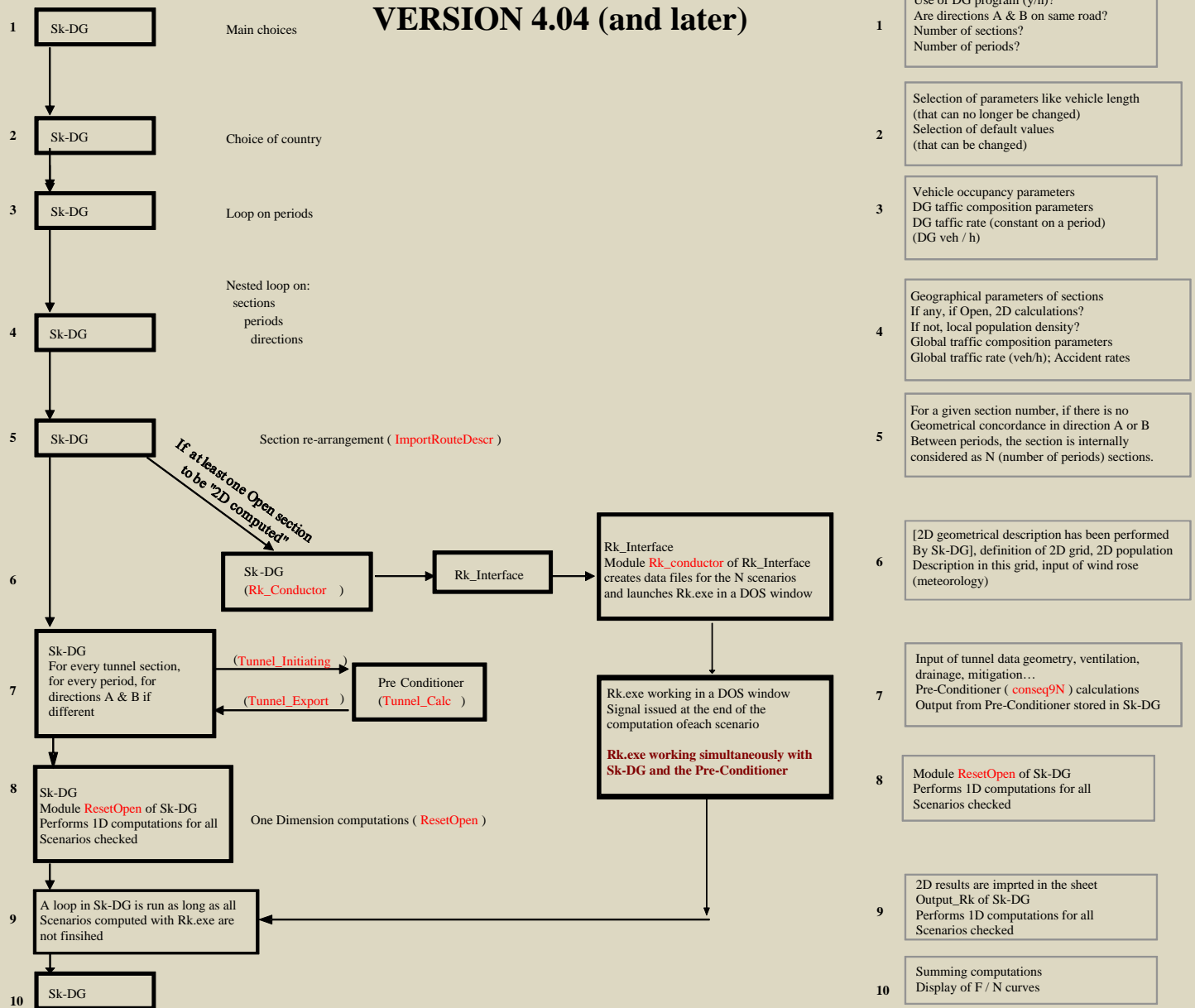


Figure 5-3: Role of Sk-DG and exchanges (input/output) with the two other modules: the Pre-Conditioner and Risk-DG (Version 4.04 and later)

6. INPUT OF DATA AND MODEL EXECUTION

6.1 INITIAL EXPLANATIONS

6.1.1 SUBDIRECTORY SAVINGS

Since version 002 of the software, major changes have been performed in the software user friendliness:

- The QRA model is launched through a small program called QRALauncher.xls(m) located in the installation directory;
- This small program is able to either run a new case or load an already existing data file (which has to be located in subdirectory “Savings”),
- Then the VBA (virtual basic application) program contained in file Spre_100.xls(m) is loaded and run.

At the end, input files are to be found in the subdirectory “Savings”, and the result files are to be found in a sub-sub-directory that has the same name that the input file. For example, if an input file is named XWF.xls(m), the related result files can be found in the “Savings\XWF\” sub-directory.

If calculations are performed for all periods, all directions and all sections together, up to 6 result files can be created from a unique input data file. The software can build results for fatalities only or fatalities + injuries. It can build curves separately for road users or local populations or both together.

2 parameters have been defined to take account of this, and those parameters are accessible to the user either through the dialogue boxes (when running a new case) or through the resulting input file. It is thus possible, for example to run firstly a case with fatalities only, local population and road users together, and then to run another case from the input file taking account of fatalities + injuries, but local populations only. The name of the result files will be composed from the name of the initial data file completed by a suffix that differs accordingly to the type of calculation as shown in Table 6-1 below:

	Fatalities only	Fatalities + Injuries
Road users + Local populations	_11	_21
Road users only	_12	_22
Local populations only	_13	_23

Table 6-1: Suffix added when composing the result file name

6.1.2 GENERAL POINTS

A unique macro-command written in Microsoft - VBA leads the user all the way through the successive stages of the risk assessment (see § 5.4 page 24).

This macro-command:

- either pops up dialogue boxes that ask for the different data that are needed and run the different calculations tools that are useful (run of a new case),
- or loads a previously defined case so that the user can modify some parameters and then the macro-command leads the user all the way through the successive stages of the risk assessment.

To answer correctly to the questions proposed by the dialogue boxes, it is very important to have gathered and put in form the necessary data before.

For a part of the data, the user will be proposed some default values (for the probabilities to get DG-HGVs involved in accidents, meteorological conditions for example).

But no default values will be provided for input that are very specific of the site like:

- the description of the routes,
- the global traffic and its composition,
- the global DG traffic rate,
- the population densities.

These data must be prepared in advance. The user that runs the QRA model for the first time can refer to the data files of the test (in subdirectory “_datafiles_samples”) to see what kind of data have to be prepared and how to prepare them.

Determining values for input data is sometimes complex, in any case there are many methodologies to calculate or estimate them according to the rough data that are collected. Thus, they should be handled with the appropriate level of expertise and consistently with the application and/or the risk assessment methodology for which the model is used.

The execution may concern routes with or without tunnels.

For the open sections, calculations may be performed with 2 very different approaches:

- a simplifying one (called 1D) where local population densities are considered as uniform along parts of the route (probabilities to get wind in a certain direction are not needed),
- a 2D description of the populations and a directional wind rose to deal with the meteorological aspects.

Dialogue boxes very early ask whether a 2D approach is used or not.

If the route includes tunnel(s), a specialised spreadsheet based tool called “ Pre-Conditioner ” is called by the general procedure and charged to deal with the tunnel sections (step 7 in Figure 5-3).

Even if some data relative to the tunnel are already known (for instance, the traffic and its composition for different periods), the Pre-Conditioner needs some additional data.

For a new case, those data are entered directly in the sheets of this Spreadsheet while a macro-command is still active in background and ready to keep on its work when you announce (by typing “ Ended ” in a specified cell) that additional tunnel data have been entered. For an already existing case, the related sheets are to be found in the input file, and can be modified prior to the running of the calculation macro-command.

The outputs representing the risk due to the tunnel sections are automatically exported to the place where they will be summed with the contributions of the open sections.

If some open parts of the route have to be calculated with a 2D approach, a specialised tool called “ Risk-DG ” will be called by the general procedures and charged to deal with these 2D computations (step 6 in Figure 5-3). This will be done only once no matter the number of open sections calculated with the 2D approach.

Most of the inputs needed by Risk-DG (or Rk-DG in short) are prepared by the Spreadsheet Sk-DG.

The outputs representing the risk in non 2D formats (like F/N curves for example) due to the open sections calculated with a 2D approach are automatically exported to Sk-DG to the place where they will be summed with the contributions of the other sections.

The 2D outputs are Excel files and may be opened and read with this spreadsheet.

6.2 RUNNING A NEW CASE

In that case, the user has to define the case through dialogue boxes. The procedure to do so is explained below. It is useful to have first prepared the data to be entered. Annex 4 entitled: "Preparing data sets" will give guidance for that.

6.2.1 USE OF THE SPREADSHEET BASED MODEL SK-DG

Before running the software for the first time, the user must have realised the installation operations (see § 5.2 page 19) successfully.

To begin a session:

- open file QRALauncher.xls(m) present in the installation directory,
- answer "yes" to the question "Do you want to run a new case?",
- click on the traffic light clipart present in the worksheet named "Welcome" (see Figure 6-1 below).

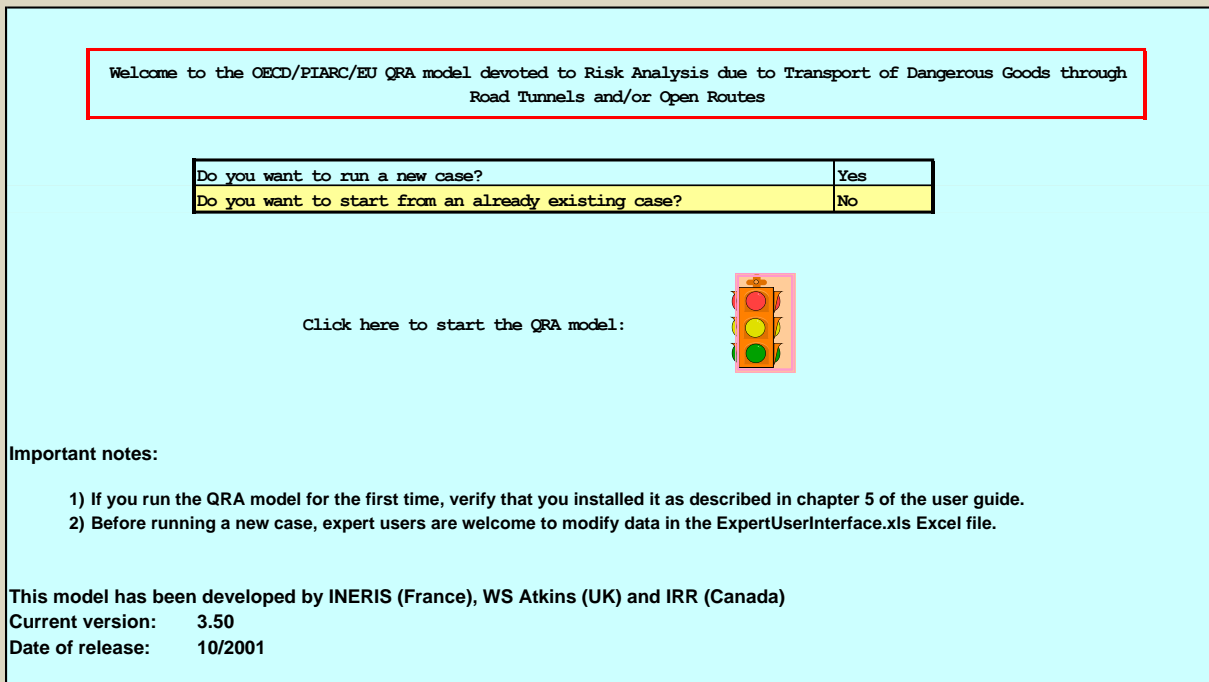


Figure 6-1 QRA launcher screen of presentation

Then, the spreadsheet based tool is run and the main VBA 5 code begins its job. After the display of a warning asking to be patient and not turn off the program during execution, and then a “disclaimer” dialogue box, the user is put in front of a dialogue box asking him the name of the file to create (this name is used to create the input file and the results files) – see Figure 6-2 below.

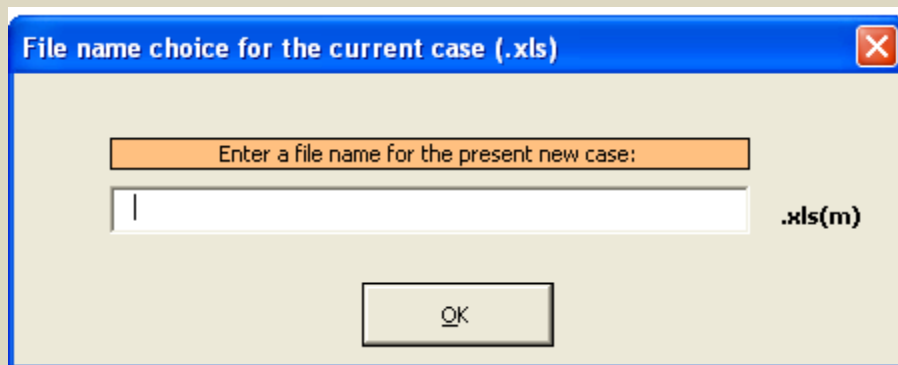


Figure 6-2: Definition of the name of the case to create

After that, the user is asked what type of results he intends to produce (see Figure 6-3 below):

- fatalities only or fatalities + injuries,
- taking account of road users + local populations, road users only or local populations only.

Preliminary Box: Choice of type of results to be produced

Do you want to produce results: for fatalities only
 for fatalities + injuries

WARNING: the production of results for injuries and fatalities requires calculation times about twice as long as for fatalities only

Do you want to produce results: for road users and local population together
 for road users only
 for local population only

WARNING: the production of results for road users and local population separately requires calculation times about three times as long as for road users and local population together

WARNING: The developers express reservations about the use and interpretation that could be performed on the basis of F/N curves concerning road users only or local population only.

Figure 6-3 Type of results to produce

After that, a set of 4 dialogue boxes is run, with additional boxes if needed.

The first one of the 4 boxes (see Figure 6-4 below) asks the user 3 questions, that invites the user to:

- indicate the intention to use or not the 2D calculation module Risk-DG (or Rk-DG in short),
- indicate if direction A and B have the same characteristics or not. If yes, all the characteristics are considered globally for both directions: geographic coordinates, traffic composition, accident rates, presence of tunnels... On the contrary, the action of answering “No” to the preceding question allows the user to define a route with geographic discrepancies between direction A and B, but also different traffic/accident rate characteristics between the two directions. For additional information regarding this choice, see chapter 8 and chapter 9.
- choose the scenarios that are to be considered (the choice is performed within a panel of 13 -as a default choice, 12 of the scenarios are checked. Only the chlorine scenario is skipped because in many countries, chlorine is not transported in large bulks-). Note that it is possible to consider a fraction of DG that can lead to heavy fires apart from flammable liquids (for instance within solid dangerous goods).

OECD QRA-model --- Dialogue Box 1/4 ✕

Do you intend to use the Fortran program Rk-DG (allows to perform 2D calculations in the Open) ? Yes No

Has directions B the same characteristics as direction A ? Yes No

Select the scenarios you intend to study:

- Scenario 1: 20MW fire
- Scenario 2: 100MW fire
- Scenario 3: BLEVE of a 50kg propane cylinder
- Scenario 4: Motor spirit pool fire
- Scenario 5: VCE of motor spirit
- Scenario 6: Chlorine release
- Scenario 7: BLEVE of a 18 tonne propane tank
- Scenario 8: VCE of propane
- Scenario 9: Propane torch fire
- Scenario 10: Ammonia release
- Scenario 11: Acrolein in bulk release
- Scenario 12: Acrolein in cylinder release
- Scenario 13: BLEVE of a 20 tonne CO2 tank
- Scenario 14:
- Scenario 15:
- Scenario 16:
- Scenario 17:
- Scenario 18:
- Scenario 19:
- Scenario 20:

Figure 6-4 First dialogue box (dialogue Box 1/4)

Scenario Nr:	Description	Capacity of tank	Size of breach (mm)	Mass flow rate (kg/s)
1	HGV fire 20 MW	-	-	-
2	HGV fire 100 MW	-	-	-
3	BLEVE of LPG in cylinder	50 kg	-	-
4	Motor spirit pool fire	28 tonnes	100	20.6
5	VCE of motor spirit	28 tonnes	100	20.6
6	Chlorine release	20 tonnes	50	45
7	BLEVE of LPG in bulk	18 tonnes	-	-
8	VCE of LPG in bulk	18 tonnes	50	36
9	Torch fire of LPG in bulk	18 tonnes	50	36
10	Ammonia release	20 tonnes	50	36
11	Acrolein in bulk release	25 tonnes	100	24.8
12	Acrolein in cylinder release	100 litres	4	0.02
13	BLEVE of liquefied refrigerated CO2	20 tonnes	-	-

Table 6-2: Main characteristics of the 13 selected scenarios

At this stage, the user should select as many scenarios as relevant to the country in which the calculation is performed. For example, scenario 6 (chlorine) can be skipped if the considered country is a country where chlorine is not transported by road in bulk tankers.

In a further stage (that is after completion of the calculations), there is a possibility in the result files to explore the influence of groupings of DG. But since calculations are long and very complex, the idea is to have all of them calculated once, their contributions kept separately. Then you will have the possibility to explore grouping influence by adding or skipping the contribution of relevant scenarios (this can be achieved by modifying the 1/0 sequencing in the pale blue cells of column K in the "List_Sc" sheet, and then by displaying the "FnCurve_UserDefined" Chart).

The second of the set of four dialogue boxes has the following aspect (see Figure 6-5 below):

Figure 6-5: Second dialogue box (dialogue Box 2/4)

This dialogue box invites the user to:

- indicate the number of sections the considered route is made of. This choice is very important because the number of sections cannot be changed in a further stage, even when running a case from the input file once it is created. So the number of sections has to be initially correct and that is why it is important to have prepared the route layout and its splitting into sections prior to begin to enter data. This has to be done accordingly to the explanations and advice given in chapter 8 and chapter 9 of the present guide. As explained in this chapter, the software allows to consider:
 - periods differing by their traffic or its composition, or local population, or a lot of other parameters such as the number of people inside of the vehicles or the frequencies to get accidents etc.
 - sections where direction A and direction B traffics pass on geographically different roads.

There is only one set of meteorological conditions (independent of the period). In case DGs are transported during specific periods (at night for instance), the time periods should be chosen accordingly and the set of meteorological conditions might be more representative of that period than average (if meteorological conditions are at hand).

- indicate the country where the routes are situated in. This piece of information is used so as to provide more pertinent default values for the accident frequency rates. The name must be entered exactly (it is case sensitive) as it appears in the list in Table 6-3, or it can be chosen in a list that appear when clicking on the related list box.
- choose the number of time periods. For each one in a later stage, a time ratio will be entered. The denominations suggest a fractionating of the day (or of the year for tourist resorts with a seasonal activity). Periods may differ by traffic and also by local population density.

1	Australia
2	Austria
3	Belgium
4	Canada
5	Czech republic
6	Denmark
7	Finland
8	France
9	Germany
10	Greece
11	Hungary
12	Iceland
13	Ireland
14	Italy
15	Japan
16	Korea
17	Luxembourg
18	Mexico
19	The Netherlands
20	New Zealand
21	Norway
22	Poland
23	Portugal
24	Spain
25	Sweden
26	Switzerland
27	Turkey
28	UK
29	USA

Table 6-3 List of countries

The layout of the third of the set of four dialogue boxes is shown by Figure 6-6. When prompted during execution, the title zone is filled in by the software and guides the user.

Figure 6-6: Layout of third dialogue box (dialogue Box 3/4)

During this phase, the user will enter data that are independent of the section number but that may vary accordingly to the period and direction. To know exactly what the entered parameters are related to, the title and label zones of this box update and prompt the period and direction indication during the whole process (see example on Figure 6-7).

Default values are proposed for the average number of people per vehicle. The colour of the corresponding text is black which means that those values may be changed by the user (see example on Figure 6-7).

Figure 6-7: Third dialogue box in case of directions A and B of the route geographically similar (Constant route characteristics) for Period Normal.

Short route description and route names are 2 zones where names and remarks related to the case and period can be defined.

If N_{per} is the number of periods, $(N_{per} - 1)$ time ratios have to be entered up to a sum of 1 for the total number of periods. So if only one period is chosen time ratio will be 1 and will appear in grey characters (which means it cannot be changed).

Three kinds of vehicles are considered regarding vehicle occupation:

- light vehicle,
- HGV,
- bus/coach.

Related to the proportion of each DG type in the DG traffic, default values are proposed that come from French, Canadian and Norwegian statistics. They are shown in Table 6-4 below. Each scenario (which is based on particular DG) is representative of a set of physical phenomena generating risk. All products that may generate these phenomena are to be considered when assessing the corresponding traffic.

	France	Norway	Canada
LPG in cylinder	0.008	0.002	0.005
All Flammable Liquids	0.363	0.352	0.301
Volatil Flammable Liquids	0.182	0.176	0.151
Chlorine	negligible	negligible	negligible
LPG in bulk	0.024	0.023	0.015
Toxic gases	0.015	0.013	0.039
Toxic liquids in bulk	0.002		0.015
Toxic liquids in cylinders	0.002		0.015
Non Flammable non toxic liquefied gases	0.013		0.008
DG potentially leading to a large (100MW) fire (except liquids)	0.006	0.005	0.005

Table 6-4 Proposed default values for the fraction of each DG type in the whole DG traffic

The user has the possibility to use another repartition of the proportions of each DG type in the DG traffic (button “ Custom ”). If so he enters in the dialog box shown in the Figure 6-8 below.

The default values correspond to a defined DG-HGV traffic that encloses both fully loaded and DG lorries assumed as being empty. In such a case, the sum related to the proportion of each DG type in the traffic must be around 0.5 or lower than that (corrosive materials for example are not represented in the set of 10 scenarios) to take account of empty lorries traffic.

When using the custom option the user can either adopt a similar approach to define both DG-HGV traffic and the proportion of each DG types, or consider only the fully loaded lorries and then define proportions of each DG types the sum of which is then equal to 1 or a bit lower. A reflexion on the way to choose this rates is presented in Annex 5

It is however important to assure consistency between the entered proportions of each DG type and the whole DG traffic.

User defined DGi/DG traffic - Form 1/1

Enter the proportion (ratio) of each DG type in the whole DG traffic for the current period

Flammable liquids in bulk (Motor spirit, diesel oil, ...):

Fraction of flammable liquids that can potentially lead to a VCE (includes motor spirit but excludes diesel oil):

Propane (flammable liquefied gases) in cylinders:

Propane (flammable liquefied gases) in bulk:

Chlorine (Rather severe toxic gases) in bulk:

Ammonia (Toxic gases) in bulk:

Acrolein (Toxic liquids) in bulk:

Acrolein (Toxic liquids) in cylinders:

Compressed CO2 (non flammable non toxic gases) in bulk:

DG potentially leading to a large (100MW) fire (except liquids):

Others (Potentially leading to at least a 20MW fire):

WARNING: The scenarios are supposed to occur on full loaded DG-HGVs. Slightly loaded DG-HGVs are to be removed when entering the proportions of each DG types to consider for further calculations

Quit Cancel Calculate OK

Figure 6-8: Dialogue box enabling choice of customised DG traffic composition.

The last of the set of four dialogue boxes has the following aspect (see Figure 6-9 below). when run for the first time.

This fourth dialog box has 3 sub parts:

- General Data
- Traffic and Local Population Data
- Accident Rates

In those three sub parts, data have to be provided.

This dialog box is proposed consecutively a number of times equal to $N_{sect} \cdot N_{per} \cdot N_{dir}$, where:

- N_{sect} is the number of sections,
- N_{per} is the number of periods,
- N_{dir} is the number of directions (1 if routes are geographically the same for direction A & B, 2 otherwise).

The user is invited first to fill in the General Data sub part before the others.

Reasons for this are:

- accident frequency rates depend on the nature open/tunnel section,
- local population densities and meteorology are entered very differently if a 2D treatment is done,

and these 2 choices are performed in the General Data sub-part.

In the sub part “General Data” of 4th dialogue box (dialogue Box 4/4), the user must first indicate if this section is a tunnel or not.

If the answer is “ Tunnel ” and if in the first dialogue box (Step 1 on Figure 6-4), it has been announced that Rk-DG would be used for 2D calculations on open section, the choice to use Sk-DG or Rk-DG has to be made for this section. Otherwise, you cannot reply, and the answer is automatically “ No ”.

This choice is offered only once per section, even if 3 periods and 2 directions have to be entered and the dialogue box comes back 5 more times for the same section.

The answer to the question “Do you intend to use Rk-DG on this section?” is stuck to “No” because it had already been “No” in the first dialog box (Figure 6-4).

OECD QRA-model --- Dialog Box 4/4

Enter the characteristics of section 1/3 for period NORMAL and direction A

General Data | Traffic and Local Population Data | Accident rates

Is This section a tunnel? Yes No

Do you intend to use Rk-DG on this section? Yes No

Coordinates of origin of this section: Abscissa (m):
 Ordinate (m):

Coordinates of destination of this section: Abscissa (m):
 Ordinate (m):

Total Length of this section (m):

CAUTION: You are not obliged to enter a length here.
In that case, the entry of the co-ordinates of the section will automatically lead to calculate a length equivalent to a straight line between origin and destination of this section.
However, if you use Sk-DG for this section, you are allowed to enter a length section greater than the one corresponding to a straight line.

Cancel << Previous Next >>

Figure 6-9: Sub-part General Data of 4th dialogue box (dialogue Box 4/4)

Co-ordinates of section extremities must be entered.

Abscissa = X-Axis co-ordinates and Ordinate = Y axis co-ordinates.

A length corresponding to the straight line between extremities will be calculated (it is not displayed). But the user may also enter a length in the cell where a “length for the current section” can be entered.

The length that will be considered for the calculations is:

- the calculated length of the straight segment between the extremities (value entered in length cell will be ignored) if Rk-DG is used for the current section.
- the maximum of the length of the straight segment and the value entered in length cell if Sk-DG is used for the current section.

In the sub part “Traffic and Local Population Data” of 4th dialogue box (dialogue Box 4/4), the user is invited to enter the characteristics of the traffic and population (see Figure 6-10 below):

OECD QRA-model --- Dialog Box 4/4

Enter the characteristics of section 1/3 for period NORMAL and direction B

General Data | **Traffic and Local Population Data** | Accident rates

Enter the traffic characteristics for this section:

Total traffic (veh/h):	<input type="text" value="888"/>	HGV/Bus average speed (km/h):	<input type="text" value="60"/>
HGV ratio (adim):	<input type="text" value=".12"/>	Number of lanes (dir A+B):	<input type="text" value="5"/>
Bus Coaches ratio (adim):	<input type="text" value=".015"/>	Delay (s) for stopping approaching traffic:	<input type="text" value="300"/>
Light vehicles average speed (km/h):	<input type="text" value="75"/>	Area (Urban/Rural):	<input checked="" type="radio"/> Urban <input type="radio"/> Rural
Average density of population (inhab/km ²):	<input type="text" value="2000"/>	This section is in the following country:	<input type="text" value="USA"/>

Figure 6-10: Sub-part Traffic and Population of 4th dialogue box (dialogue Box 4/4)

About the parameters to enter in the second sub part, one can note the following:

- About total traffic, if there is only one period it is the AADT (average annual daily traffic) without any weighting for HGVs, if there are different periods, it is the "AAPT" (average annual traffic for the period), still without weighting for heavier vehicles. The AAPTs for all periods weighted by the period time ratios should equal the AADT. Total traffic is for one direction if directions A & B are separated, it is the total of both if they are not separated in the computations.
- About HGV ratio, it is the number of HGVs (including those transporting DGs) divided by the total number of vehicles,
- About Bus/Coaches ratio, it is the number of bus or coaches divided by the total number of vehicles,
- About Light vehicle and HGV/Bus average speed, they are used in order to:
 - Calculate the conditional probabilities of DG scenarios once an accident occurs,
 - Calculate the density of road users on route sections where traffic is fluid.
- About the number of lanes (dir A+B) parameter: In fact, if entering twice the same section at the same period because directions A and B are separated somewhere on the route, THE USER MUST INDICATE ONLY THE LANES OF THE DIRECTION (S)HE IS ANSWERING FOR !

But if A and B are treated together, the user indicate the total number of lanes A+B.

- About the delay for stopping approaching traffic: This parameter is used to limit the possible extension of a traffic jam after an accident has taken place (and in some cases before the scenario has occurred), if a safety plan exists in case of an accident involving a DG-HGV for the considered section. It is often the case for tunnel section: the traffic will be diverted within a short delay to avoid a worsening of the consequences of a possible scenario. This delay should be entered here. On the contrary, if nothing is planned to divert rapidly the traffic in case of an accident involving a DG-HGV, the user is invited to enter an important delay, for example 9 000 seconds.
- About the Urban/Rural parameter. It is difficult to draw a limit between those two types of area. Cities are urban, countryside is rural. But between, there is a continuity and the dichotomy between Urban and Rural is rough. Nevertheless, a sensitivity analysis showed that FOR THE SAME TRAFFIC and the same LOCAL POPULATION DENSITIES, the parameter Urban/Rural has a very limited influence.
- About the average density of population: This parameter is accessible to the user only if the considered section is a tunnel section or an open section for which Rk-DG is not used. On open section for which a 2D calculation is planned, the population is entered later in a 2D grid.

In the sub part named "Accident rates" of 4th dialogue box (dialogue Box 4/4), the user is invited to define the way the accident rates will be entered (see Figure 6-11 below):

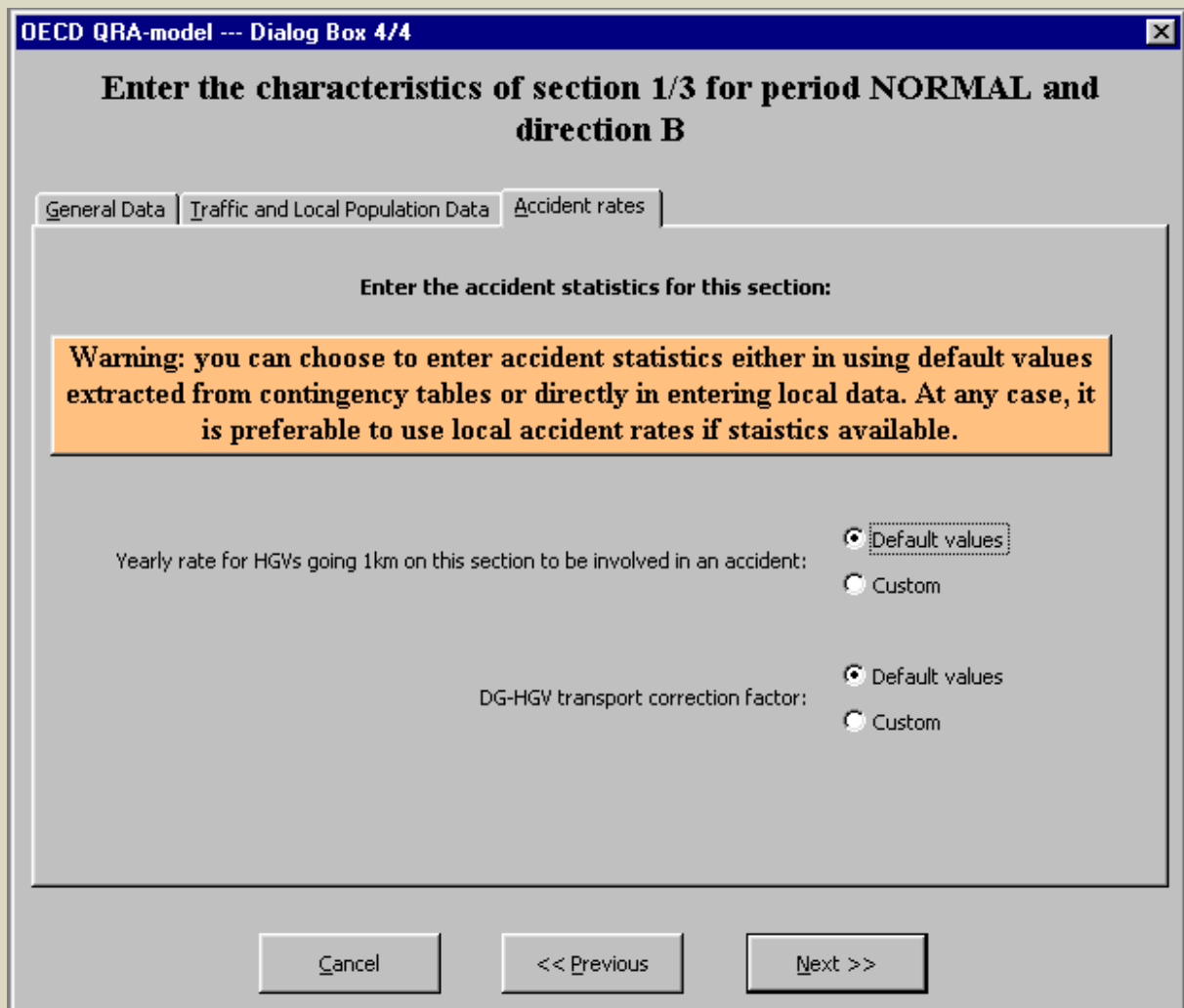


Figure 6-11: Sub-part Accident rates of 4th dialogue box (dialogue Box 4/4)

HGV traffic accident frequency rates (expressed per HGV*km) depend of a lot of parameters (even the countries).

Very few statistical studies were available, especially for accidents inside tunnels. From them, traffic accident frequency rates have been extracted. They have been set as Default values for different countries (or continents).

HGV traffic accident frequency rates depend of the type of road. Number of lanes is used when taking out of the contingency tables the relevant default values.

Precise knowledge of HGV traffic accident frequency rates would lead to wrong conclusions if DG-HGV drivers are more cautious, have better equipment and have finally less accident than other HGVs. In that case, a correction factor is needed if one wants to use the HGV traffic accident frequency rates. This is accounted for.

Nevertheless, it is always better to use local data if they are available. This option is offered for the HGV accident rates and also the DG/HGV correction factor.

Accordingly to what the user decides: take out of the contingency tables (default values) or choose by himself, the form of the dialog boxes will be different. But the philosophy remains the same.

6.2.2 USE OF THE PRE-CONDITIONER (TUNNEL SECTIONS)

During development of the Pre-Conditioner, the word “ SEGMENT ” has been used to characterise sub sections of the tunnel section. A tunnel is always a unique section for Sk-DG.

But for assessment inside of the tunnel, it has been divided into a certain number of segments.

Many parameters may vary from a segment to another, but a few others are indicated once only and keep the same value in all segments.

These parameters are width, height, camber, drainage layout, mean distance between emergency issues, tunnel structure.

And so it is not possible to take precisely into account variations of those few parameters in the tunnel.

This is a limitation of the model.

The user is led to the Pre-Conditioner by Sk-DG. He arrives in a sheet called “ Tunnel Inputs ”. He must stay in this sheet and not go anywhere else.

When all the data are entered (in the blue cells), he has to select “ Ended ” in cell D94. This will start tunnel calculations and their exportation to Sk-DG.

Important notes:

- Tunnels may or may not contain devices with flammable characteristics. Those characteristics are then liable to worsen the effects of a fire scenario as considered in the QRA. Such a worsening effect is not considered in the QRA.
- Chapter 9 (page 83) is devoted to the way the user must manage the input of data relative to diverse types of tunnel. In particular, additional guidance is provided to define normal and emergency ventilation.
- Version 3.60 checks the data entered in the “Tunnel inputs” sheet. Errors are displayed with a red background, warnings with a pink one. It is normal to get errors and/or warnings while the data are not completely entered. But they should have disappeared when data are complete. Computations should not be performed in case of data errors. Presence of errors is displayed (with red background) in cell E94 of sheet Tunnel inputs in the file Conseq. Computations are launched by entering “Ended” in the cell nearby (“D94”). In case of a new computation of a case already saved, the user has no need to look at cells D94 and E94, but the program stops automatically computations in case of errors reported in cell E94.

6.2.2.1 TUNNEL DESCRIPTION

This section describes the inputs which must be entered by the user. The values should be entered directly in the appropriate cells. Since the lengthwise geometry of the tunnel is defined in terms of segments, certain parameters will need to be specified at a number of locations along the tunnel. Normal spreadsheet operations may be used to duplicate values along a row.

6.2.2.2 GEOMETRY (TO BE ENTERED: BLUE CELLS)

The following inputs have to be entered by the user to describe the cross-section geometry:

effective width (m) [row 5]

effective height (m) [row 6]

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Tunnel 1 inputs			symbol	units	data								
2														
3														
4	cross-section geometry													
5	effective width	W	m	10.5										
6	effective height	H	m	4.55										
7	open cross-sectional area	A	m ²	47.775										
8	camber	Cam	%	2										
9														
10														
11	lengthwise geometry													
12	...segments (homogeneous - ventilation, gradient)													
13	total number of segments	Ns	-	7										
14	segment number	-	-	1	2	3	4	5	6	7				
15	segment lengths	Xs	m	1425	1424	1157.5	1157.5	1146	1146	1146				
16	total length of tunnel	Xt	m	9602										
17	segment gradient	Gs	%	1.65	1.65	1.65	1.65	-0.5	-0.5	-0.5				
18	...nodes (segment start and end points)													
19	total number of nodes	Nn	-	8										
20	node number	-	-	1	2	3	4	5	6	7	8			
21	location of node	Xn	m	0	1425	2849	4006.5	5164	6310	7456	8602			

Figure 6-12 Layout of the cells containing the geometrical parameters.

The effective width and height will need to be estimated for circular cross-section tunnels as illustrated in Figure 6-12. Care should be taken to ensure that the cross-sectional area is correct. It is important to appreciate that both parameters are used in calculating physical parameters such as smoke layer depths and pool areas, so it would not necessarily be appropriate, for example, to use the maximum height and a reduced effective width or the maximum width and a reduced height. In some cases, it may be appropriate to check how much the results vary according to the choice of width and height.

camber (%) [row 8]

The lengthwise geometry is defined in terms of segments as illustrated in Figure 6-13. Note that portals A and B are defined according to the order in which route sections are defined. Within each segment, the gradient and ventilation extract rate are assumed to be constant. Camber is assumed to be constant along the whole tunnel bore (use average camber).

The inputs are as follows:

total number of segments (-) [row 13] This number was limited at 15 in version 3.61. Version 4.10 accepts a maximum of 35 segments.

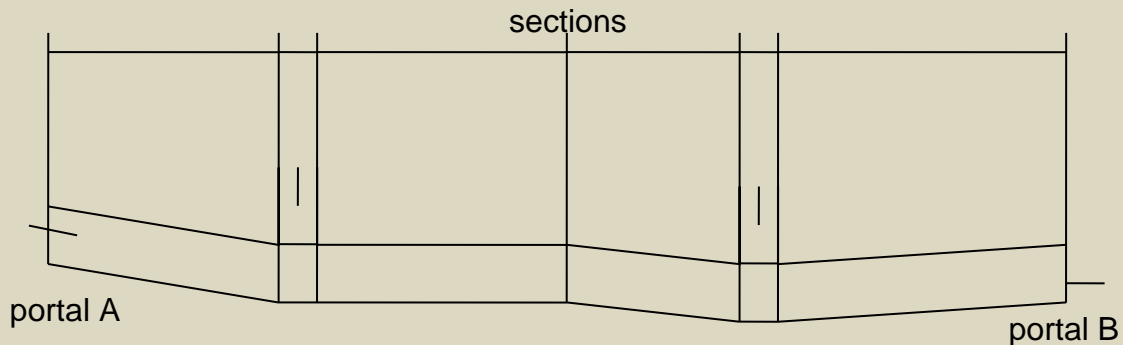


Figure 6-13 Representation of a tunnel using segments

segment lengths (m) [row 15] The length of each segment (except the first one in cell D15 yellow background) must be entered along this row of cells. According to the number of segments specified, the segment numbers are output as a prompt in the row above.

The total length of the tunnel, known from the input realised before in Sk-DG (route description), is stored in cell D16. Content of cell D15 (orange background) is obtained as the difference between the total length and the sum of the length of the other segments. In version 3.60 and later, a test checks that lengths are well entered.

segment gradients (%) [row 17] A value is required for each segment. A positive gradient corresponds to a segment of tunnel which slopes upwards when travelling from A to B.

The junction between 2 consecutive segments is called a node. A first node corresponds to portal A, a last one to portal B. The number of nodes is equal to the number of segments +1. The node parameters are calculated automatically from the segment data entered by the user. The parameters include the number of nodes [row 19] and the locations of the nodes [row 21].

6.2.2.3 VENTILATION (TO BE ENTERED: BLUE CELLS)

Information needs to be entered to describe the ventilation conditions which exist normally and those conditions which are activated in the event of an emergency. For many tunnels, the emergency ventilation varies according to the location of the accident. To cater for this, the user is currently allowed to specify up to 10 different emergency ventilation regimes in addition to the normal regime.

For each ventilation regime, the user is required to enter two sets of data:

- the net ventilation flow rates along the tunnel at each node, which is:
 - direction A: positive if it goes in the traffic direction
 - direction B: negative if it goes in the traffic direction
- and the extraction flow rate for each segment which cannot be negative.

The effects of ventilation supply flows into the tunnel at different segments may be accounted for when specifying the flows along the tunnel. Thus, for example, a semi-transverse ventilation system with supply ducts along the tunnel would have flows along the tunnel varying with location, whilst extraction flows would be set to zero.

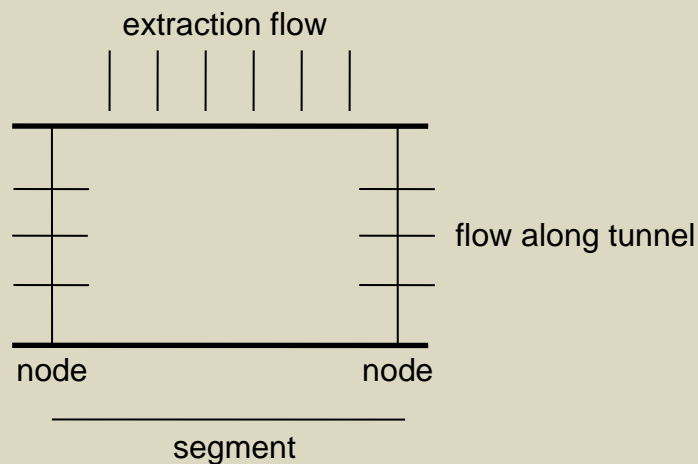


Figure 6-14 Definition of ventilation flows

When entering node and segment values, note that the node and segment numbers are indicated in the preceding rows as a prompt.

For each segment, ventilation is in fact defined by 4 flows which are dependant through a conservation law, so that only 3 data are needed.

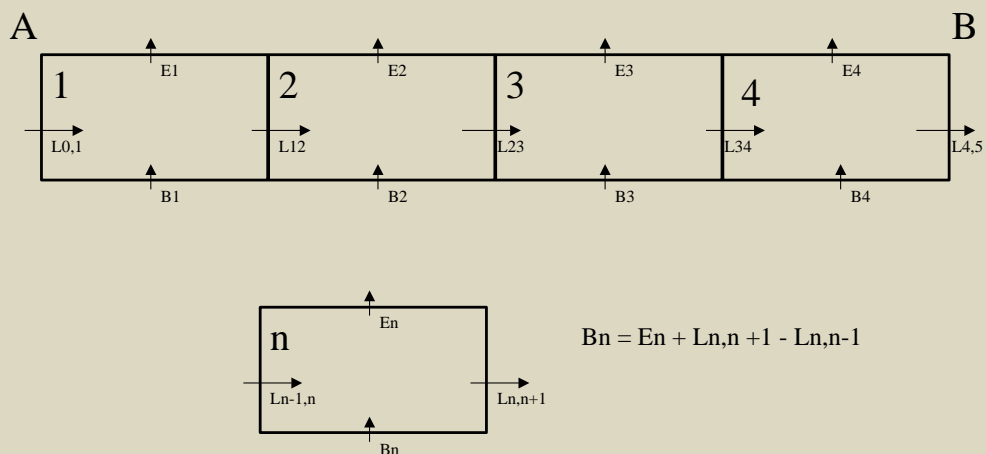
Figure 6-15 below shows a tunnel divided into 4 segments.

Ventilation is defined in each segment by 3 data:

- $L_{n-1,n}$ longitudinal flow coming from Portal A,
- $L_{n,n+1}$ longitudinal flow going to Portal B,
- E_n flow extracted.

B_n , flow of supplied (fresh) air in segment n is given by relation:

$$B_n = E_n + L_{n,n+1} - L_{n,n-1}$$



In order to work correctly, the model requires that supplied air flows are negative in no segment. To check that, a test has been added in version 3.60. If a negative supplied air flow is found, execution is stopped and indications about what should be corrected given to the user.

Figure 6-15 Relations between longitudinal and transversal air flows

ventilation - normal

volume flow rate extracted from tunnel (m³/s) [row 27] In case air goes out transversally (whether it's mechanically extracted or not), a positive value needs to be entered for each segment (no value is considered as zero).

volume flow rate along tunnel (m³/s) [row 30] A value needs to be entered for each node (positive or negative according to direction).

ventilation - emergency

number of emergency ventilation regimes (-) [row 34]

time taken to activate emergency ventilation (minutes) [row 35] This parameter can be used to take account indirectly of the presence, for example, of automatic fire detection systems or CCTV.

emergency ventilation regime if accident within this location (-) [row 37] The number of the relevant regime that should be applied for a fire within the respective location (segment) should be entered for each segment. In version 3.60 a test has been added in order to check that correct values are entered where they are needed.

volume flow rate extracted from tunnel (m³/s) [rows 41 to 50] One row of segment values to be entered for each ventilation regime (no negative values).

volume flow rate along tunnel (m³/s) [rows 54 to 63] One row of node values to be entered for each ventilation regime (positive or negative according to direction).

An example of ventilation system is shown below:

23										
24	ventilation - normal									
25	...segments									
26	segment number	-	1	2	3	4	5	6	7	
27	volume flow rate extracted from tunnel	YsN	m ³ /s	0	0	0	0	0	0	0
28	...nodes [segment start and end points]									
29	node number	-	1	2	3	4	5	6	7	8
30	volume flow rate along tunnel at nodes	YnN	m ³ /s	42.3	42.3	42.3	42.3	42.3	42.3	42.3
31										

Figure 6-16 example of ventilation system

6.2.2.4 DRAINAGE (TO BE ENTERED: BLUE CELLS)

Drainage systems in current use include those with discrete drainage points spaced along the length of the tunnel and those with continuous slots. The consequence modelling requires two inputs:

open area of discrete drains or continuous slot (m²) [row 67]

interval between drains, or slot length used to define the open area (m) [row 68]

For discrete drain systems, the area corresponds to the open area of a drain cover whilst the interval corresponds to the spacing between such drainage points. For continuous slot systems, the parameters are taken to represent the open area corresponding to a specified length of open slot. For example, a continuous slot with a width of 0.06 m would have a open area of 0.06 m² corresponding to a characteristic length of 1 m.

6.2.2.4.1 TRAFFIC (FOR INFORMATION: ORANGE BACKGROUND)

Traffic has been described in Sk-DG using two parameters: traffic direction and traffic density. The two parameters have been passed over to the Pre-Conditioner and are used to provide a qualitative description of the blockage effect of traffic in the tunnel subsequent to an accident. In the event of an accident, it is assumed that traffic in front of the accident can leave freely, whilst traffic behind the incident is stationary. The blockage effect is considered in the calculation of explosion consequences and evacuation.

Warning: the risk assessed by the QRA will be underestimated for accidents occurring whilst downstream traffic is already blocked and cannot leave the tunnel.

traffic direction (-) [row 72] The meaning is:

- 1 uni-directional traffic from B to A
- 0 bi-directional traffic
- 1 uni-directional traffic from A to B.

You do not have to modify the values here. This has been done by Sk-DG accordingly

traffic density (-) [row 73] It is assumed that all available lanes are fully occupied with vehicles. This parameter indicates the proportion of vehicles which are HGVs or of a similar size (i.e. including large buses, etc.). The meaning is:

- 0 empty tunnel (no traffic apart from DG transport)
- 1 'light' - large vehicle density of about 10%
- 2 'normal' - large vehicle density of about 40%
- 3 'heavy' - large vehicle density of about 75%

6.2.2.4.2 MITIGATION MEASURES (TO BE ENTERED: BLUE BACKGROUND)

There are two inputs required under this heading. Both parameters are used in the calculation of tunnel occupants' exposure time, taking account of the possibilities of evacuation.

average spacing between emergency exits (m) [row 77]

type of emergency communications (-) [row 78] The options available are:

- 0 None
- 1 bell/siren
- 2 PA (public address system)
- 3 PA+CCTV

6.2.2.5 TUNNEL STRUCTURE (TO BE ENTERED: BLUE BACKGROUND)

type of construction (-) [row 82] The options available are:

- 1 drill and blast or TBM (tunnel boring machine) - circular cross-section
- 2 cut and cover - rectangular cross-section

ground type (-) [row 83] The options are:

- 1 bedrock
- 2 fragmented
- 3 fragmented and under water

If the tunnel was constructed by drill and blast or TBM techniques, then it is assumed to have a circular cross-section. Two specific inputs are required:

internal radius (m) [row 84]

lining thickness (m) [row 85]

Alternatively, if the tunnel was constructed by cut and cover techniques, then it is assumed to have a rectangular cross-section. Two specific inputs are required:

There is usually some form of internal structures within the tunnel, eg. Road support or dividing wall. The inputs are:

road support thickness (m) [row 86]

mid-wall thickness (m) [row 87]

The next two inputs relate to the overburden.

overburden depth (m) [row 88]

depth of water above solid overburden (m) [row 89]

The presence of fire protection lining may have a significant effect on the degree of extent of damage occurring in the event of a fire or explosion. Three inputs need to be entered:

fire protection lining (-) [row 90] The options are:

- 0 none
- 1 yes

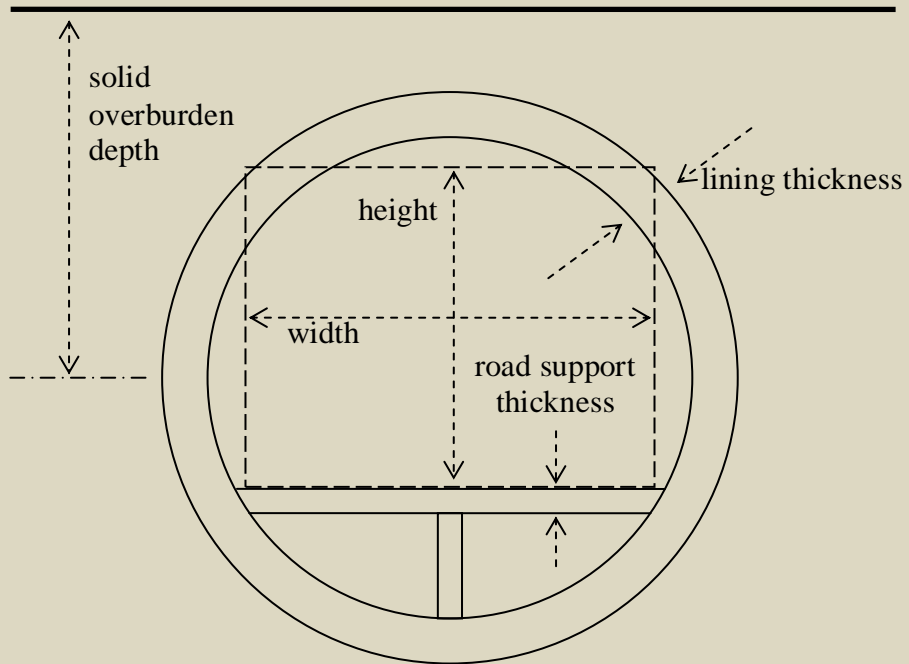
temperature rating (deg.C) [row 91]

time rating (minutes) [row 92]

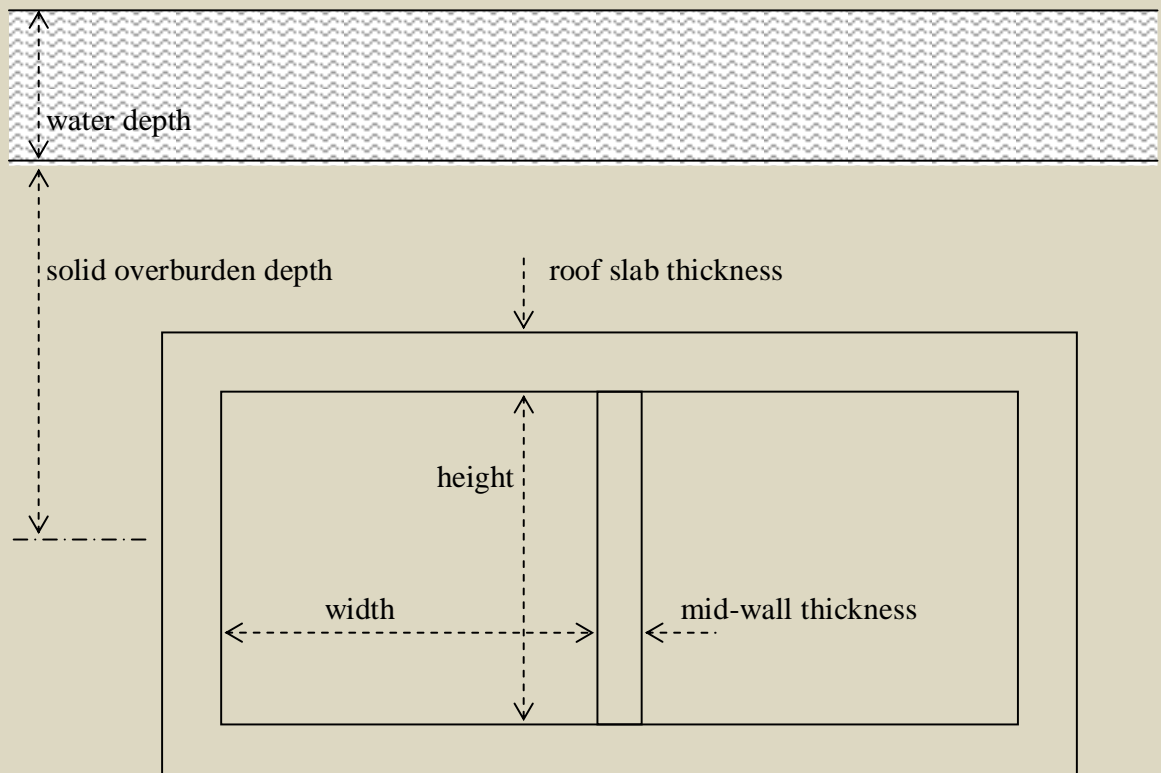
The temperature and time rating parameters provide an approximate way of accounting for the effects of specific temperature-time curves for fire protection materials.

6.2.2.6 INFORMATION ON ADDITIONAL INPUTS

Whilst the user enters segment-based information, the actual calculations may be performed using sub-segments to provide better resolution of the events. It is suggested that the sub-segment length should be determined by subdividing the average spacing between emergency exits by a factor of 4. Thus, for a 7.5km tunnel with emergency exits at 300m intervals, there would be 100 sub-segments. For long tunnels, it may be necessary to use fewer than 4 sub-segments between emergency exits. The calculation of sub-segment length is simple and is given in [row 97]. The total number of sub-segments is reported in [row 100].



a.) circular section tunnel with solid overburden



b.) submerged rectangular section tunnel

Figure 6-17 Examples of tunnel geometry definition

6.2.3 USE OF THE FORTRAN PROGRAM RK-DG (2D CALCULATIONS FOR OPEN SECTIONS)

The specificity of this program is to be run in a DOS (32 bits) environment.

The macro-command active in Sk-DG creates a list of Input files (prepared before the execution of the DOS command and placed in sub-directory « Rk-DG\Data » [see Figure 5-1]) and then a list of input that will be fed to the Rk.exe executable file (during its execution). These indicate:

- the number Nper of periods and their time ratios,
- the 2D population density files for each period
- the number Ndir of sections,
- the characteristics of the Nper*Ndir routes to consider,
- the meteorology file to use.

6.2.3.1 ENTERING 2D POPULATION DENSITIES

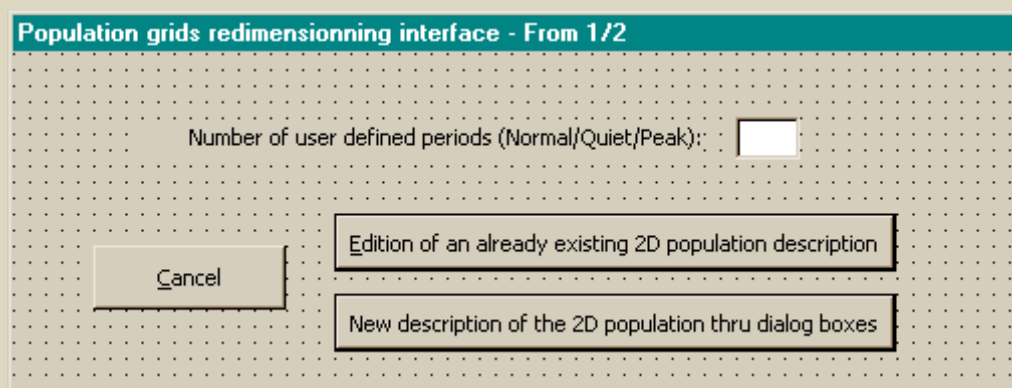


Figure 6-18 First dialogue box for input of population

It is possible to enter as many 2D population grids as there are periods.

It is possible to define cells of any dimension (rectangle or squares with dimensions varying from 1 m to 1000 m). However, it is recommended to define the cells as squares, with, for example, side length of 200 or 250 m.

During calculations, these grids will be split into n^2 sub-squares, and the assumption will be made that the population present in the cell is equally distributed in each sub-cell.

A value of n is chosen. Each sub-cell has a side length of around 70 m. This is a good compromise between very long computations (time is proportional to n^3) and a lack of precision in results.

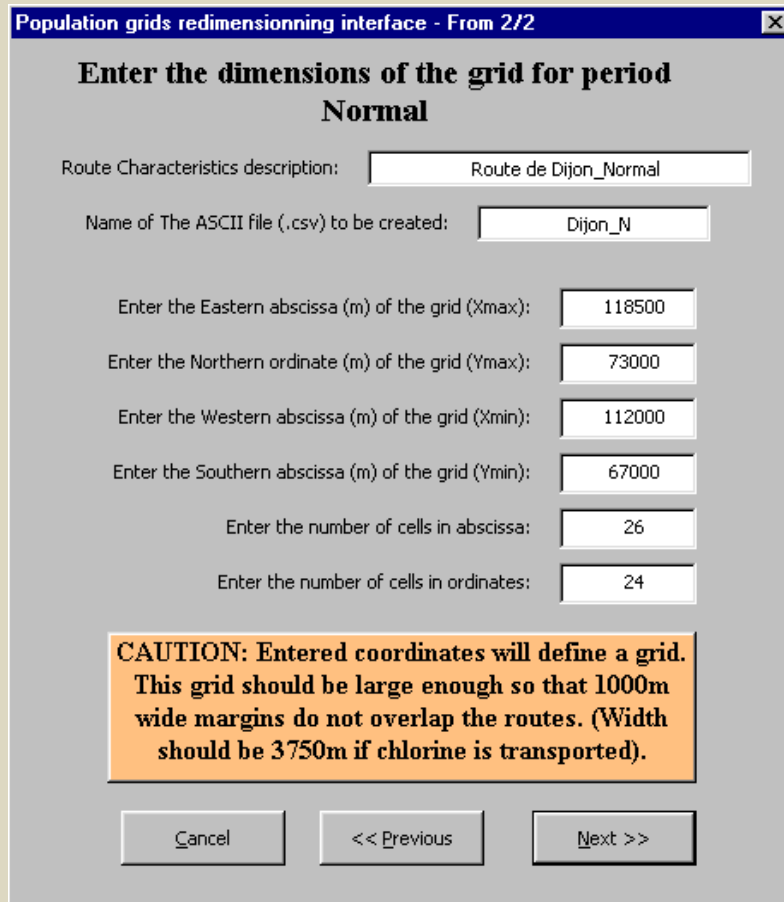


Figure 6-19 Second dialogue box for input of population

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1	Normal		Route de Dijon_Normal																								
2																											
3																											
4																											
5																											
6																											
7																											
8																											
9																											
10																											72750
11																											72500
12																											72250
13																											72000
14																											71750
15																											71500
16																											71250
17																											71000
18																											70750
19																											70500
20																											70250
21																											70000
22																											69750
23																											69500
24																											69250
25																											69000
26																											68750
27																											68500
28																											68250
29																											68000
30																											67750
31																											67500
32																											67250
33																											67000

Figure 6-20 Example of grid for population density description

Number of periods: (1, 2 or 3). This is just a remainder of a choice operated earlier in the input of data.

Route characteristics description: it is just a title that will help to remember what population or period has been considered (it is not limited at 256 characters).

Name of the ASCII file to be created: do not put any sub-directory indication, this will be handled by the program itself. The program will also add at the end of your file name “_N” if it is related to a normal period, “_Q” if it is related to a quiet period, and so on. Maximum number of characters allowed is 25 (Risk--DG version 3.08).

Input of the 4 extreme co-ordinates:

Grid that will be generated has a rectangular shape and is defined by 2 points:

South-West corner
North East corner

Each one of these 2 points is declared by 2 co-ordinates.

It is possible to use either absolute data referring to map co-ordinates, or co-ordinate relative to an origin (for instance South West corner by taking $X_{min} = Y_{min} = 0$). At any case, these co-ordinates must be expressed in meters.

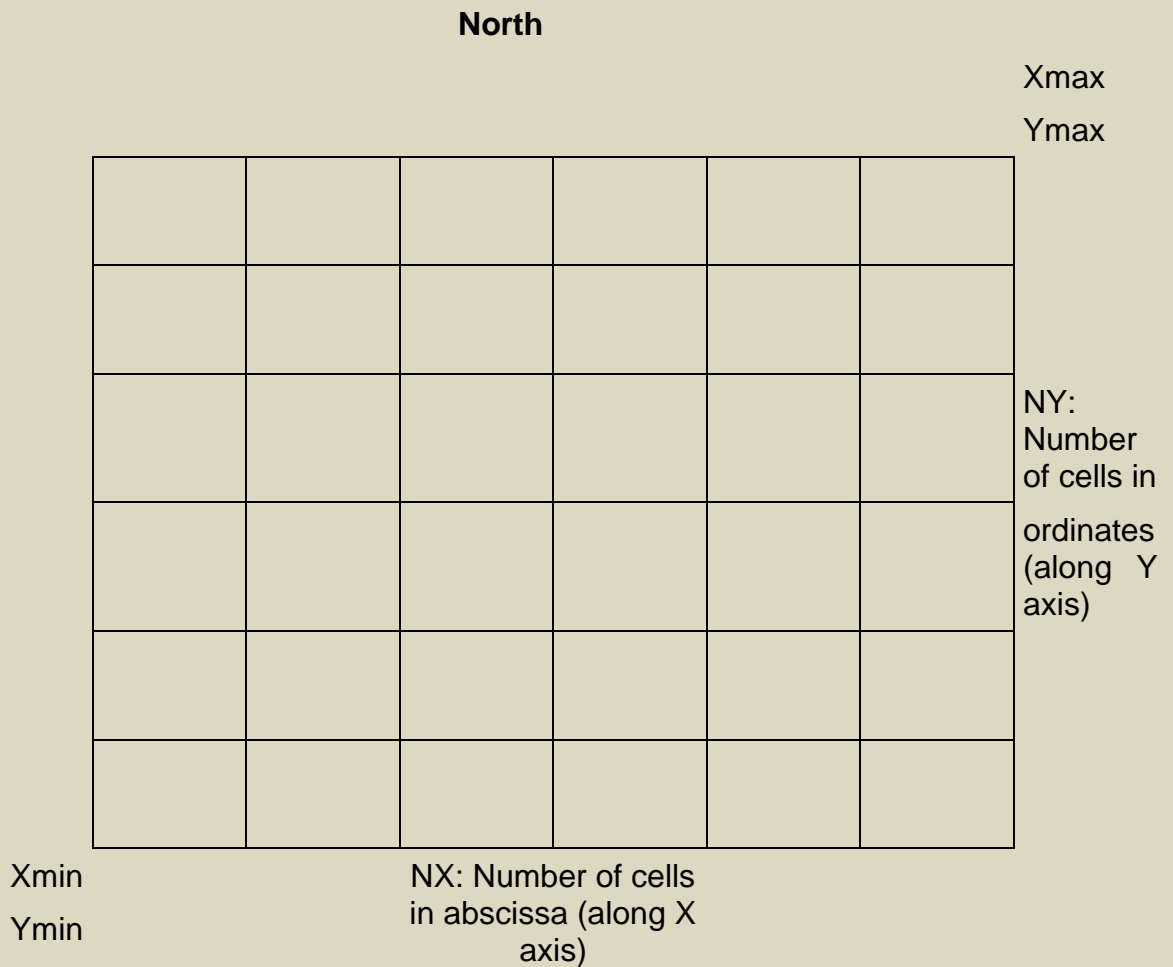


Figure 6-21 Organisation of grid for population density description

Number of cells along the axis: This enables the division of the covered area in NX*NY cells (NX and NY are integers).

They should be chosen so as to get cells that are squares exactly or approximately. It means one should have: $(X_{max} - X_{min}) / NX$ close to $(Y_{max} - Y_{min}) / NY$.

Maximum authorised values for NX and NY are 120 (Risk--DG version 3.07).

CAUTION: Entered co-ordinates will define a grid. This grid should be large enough so that 1000m wide margins do not overlap the routes. (Margin width should be increased to 3750m if chlorine is transported).

Once the inputs are completed the activation of the " NEXT " button paste the right values in the upper part of sheet pop_01 and formats a grid with the right numbers of rows and columns.

The “ NEXT ” button has to be pressed as many times as there are periods. Sheets pop_02 and pop_03 are activated if needed. In these additional sheets, it is possible to change the route characteristic description and the ASCII file name, but not the grid definition parameters (Xmin, Ymin, Xmax, Ymax, NX, NY).

It is important to note that:

- Sheet pop_01 is always used for NORMAL period,
- Sheet pop_02 is always used for QUIET period
- Sheet pop_03 is always used for PEAK period.

All the cells of the grids have to be filled in with the number of people (excluding road users) present during the considered period in the area represented by the cell.

This may be done:

- either manually cell after cell
- or more rapidly by pasting the content of an already existing file.

The pale blue background may be changed and the user may devise its own colour coding (for example parts that remain unchanged from a period to another one).

6.2.3.2 METEOROLOGY DESCRIPTION

The wind plays a major role in the dispersion and drifting of a toxic or explosive cloud.

Meteorological conditions concern: the probabilistic description of the wind.

As already stated in § 6.2.1, there is only one set of meteorological conditions (independent of the period). In case DGs are transported during specific periods (at night for instance), the time periods should be chosen accordingly and the set of meteorological conditions might be more representative of that period than average (if meteorological conditions are at hand).

Meteorological conditions may be presented in 2 different ways:

- as a distribution accordingly to the wind direction and the wind velocity: (wind rose),
- as a distribution accordingly to the wind velocity only.

6.2.3.2.1 DIRECTION DEPENDANT METEOROLOGY DESCRIPTION

If 2D calculations are performed, a direction dependant meteorology description is needed.

The input of corresponding data is performed through dialogue boxes.

Wind Rose entry - Form 1/2

Do you want to edit the wind rose edited for the last calculation? Yes No

Wind rose short description:

Name of The ASCII file (.csv) to be created: **no capital letters**

Number of angular sectors (min=4, max=36):

Figure 6-22 First dialogue box for meteorology description

Wind Rose entry - Form 2/2 [X]

Enter the meteorological characteristics for sector 2/18 of the Wind Rose

Angle (°) from North corresponding to sector 2

WARNING: The 0° sector corresponds to a wind blowing southwards

Sum of time ratios entered so far:

Time ratio for calm winds (< 2m/s) with this direction (sector):

Time ratio for winds between 2m/s and 5m/s with this direction (sector):

Time ratio for winds between 5m/s and 8m/s with this direction (sector):

Time ratio for winds blowing faster than 8m/s with this direction (sector):

Figure 6-23 Second dialogue box for meteorology description

Is this wind rose the same as the previous one ?

In case of a new site, the answer is usually “ NO ”.

The answer “ YES ” should be used cautiously. It has been implemented so as to avoid to re-enter a full wind rose for a user having already run computations on a site and making new calculations on the same site after some modifications of the input data.

Answer “ YES ” will take the previous wind rose but change the file name and the short description accordingly to what appears in corresponding cells in the dialogue box.

Wind rose short description: it is just a title that will help to remember what city or meteorological station has been considered (it is not limited at 256 characters).

Name of the ASCII file to be created: do not put any sub-directory indication, this will be handled by the program itself. The program will also add at the end of your file name “ _N ” if it is related to a normal period, “ _Q ” if it is related to a quiet period, and so on. Maximum number of characters allowed is 25 (Risk--DG version 3.07).

Filling up the wind rose:

This is done iteratively sector after sector. The sectors are defined by the angle of their bisector with the north direction. The angles are indicated in degrees.

Angle 0 corresponds to a wind coming from North and blowing southwards.

Angle 90 corresponds to a wind coming from East and blowing westwards.

Time ratios correspond to yearly probability. Because of variability from a year to another, the wind rose should be computed on several years (15 or more if possible).

The sum of the time ratios must be 1.

This leads generally to a problem, because, meteorological stations do not indicate wind directions for slow winds (slower than 1, 1.5 or 2 m/s). For this reason the sum of the reported ratios is less than 1. (It is not rare to get reported observations of velocities of more than 2 m/s that represent only half of the year). The missing part must be re-entered in the N (number of sectors) lower than 2 m/s time ratios. For simplifying reasons, this splitting may be performed in equal parts

When the wind rose is completed, a graph appears and enables to visually check the validity of the input.

Important note: Normally, the run of Rk-DG ends on a message telling “Normal end of calculations”. The user has to wait until this message appears before continuing with Sk-DG. If an error message occurs in the DOS window, the user must key in “Carriage Return”. In some cases, the calculation will continue, and the program will come to a normal end. If it is not the case, the whole program will end abnormally.

6.3 RUNNING AN ALREADY EXISTING CASE

In that case, the user will load an existing input file. The procedure to do so is explained below.

At the very beginning, the procedure is very similar to the one corresponding to the run of a new case/

To begin a session:

- open file QRALauncher.xls(m) present in the installation directory,
- answer “No” to the question “Do you want to run a new case?”,
- click on the traffic light clipart present in the worksheet named “Welcome” (see Figure 6-24 below).

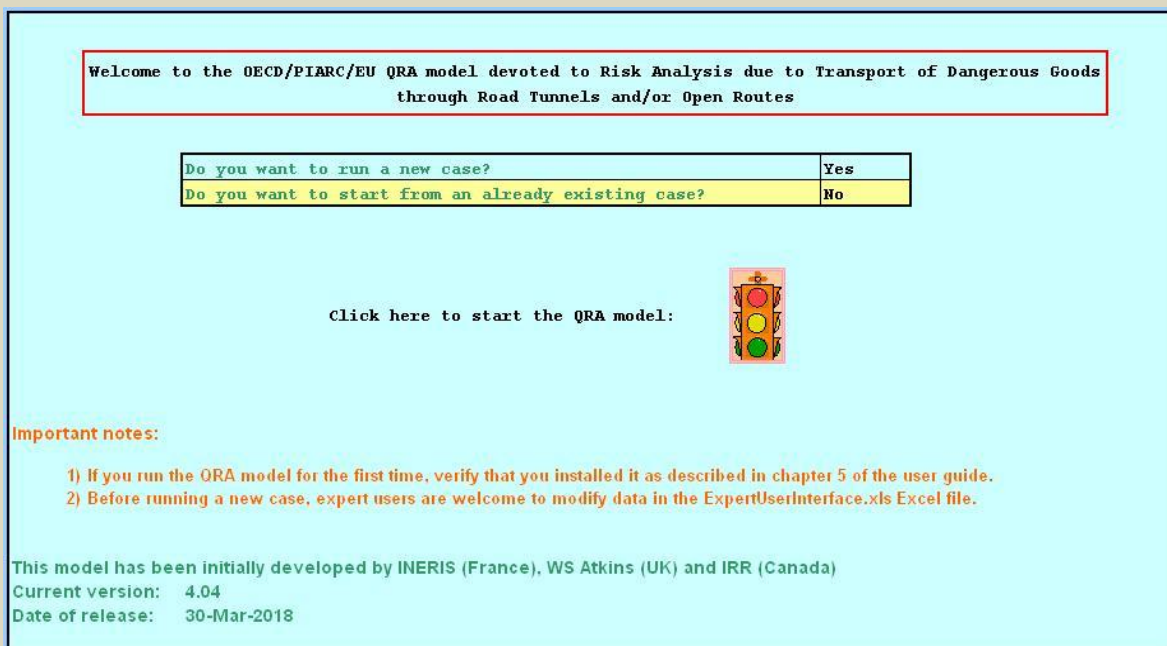


Figure 6-24 QRA launcher screen of presentation

Then the launcher displays a dialogue box (see Figure 6-25 below) that allows the user to choose between all the already existing cases located in subdirectory “Savings” with extension “.xlsm” but also “.xls”. In case a file with extension “.xls” is chosen, a warning is displayed. If the user confirms his intention to use the extension “.xls”, the file is used if and only if there is no file with the same name and extension “.xlsm” that could be overwritten because, the .xls file will be converted to format “.xlsm” before the calculations.

Notes to the users:

- When the list of existing files tends to be too long, the user has the possibility to remove some of those cases from the “\Savings\” sub-directory (and store them elsewhere). To remove completely a case, it is necessary to remove the input file but also the result files present in the sub-directory of the same name than the input files.

- In version 3.61 in case there was no data file in the “\Savings\” sub-directory, there was no way to get out of the dialog box of Figure 6-25 below and no way to stop Ms-Excel. In version 4.04 and later, an “Exit” button has been added and the user may quit the QRA easily (rebooting is no more needed):

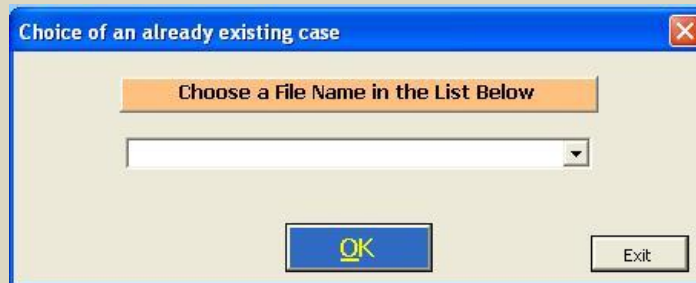


Figure 6-25 Choice of an already existing case

Then the QRA launcher opens the related file, and the macro-command ends on a message box (see Figure 6-26 below) telling that the user has now the possibility to modify some parameters of the loaded case, and then that he should click on the clipart of the “Initial_Inputs” worksheet to run the QRA on the basis of the modified loaded case. The initial disclaimer and dialogue box do not appear, if DG-QRAM is started from an already existing case.

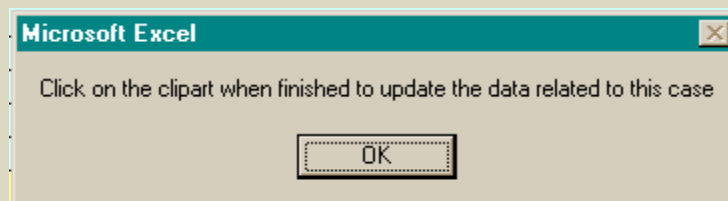


Figure 6-26 Message box appearing when loading an already existing case

The first sheet that appears to the user is named “Initial_Inputs”. It contains some general information related to the case (see Figure 6-27 below):

- The file name. This name can be changed. In that case, the modifications of the case are saved in a new file, and the related results are created in a new sub-directory. From a general point of view, it is recommended:
 - not to rename the case when only modifying the type of results to produce (i.e. calculations for fatalities/fatalities+injuries, calculations for road users/local population/both),
 - to rename the case in all other situations.
- The country where section 1 is located,
- The selection of the considered scenarios,
- The type of calculations to perform. Calculations for fatalities only are associated to number 1 and calculations for fatalities + injuries are associated to number 2. Calculations for road users and local population together are associated to another number 1, calculations for road users only are associated to number 2, and calculations for local population only are associated to number 3.

1) Data that are constant all along a route, but that can be modified as a function of time period and travel direction															
Route name		SOpen_NORMAL													
Route description		Somportroute													
Average number of persons in a car		2													
Average number of persons in a HGV		1.1													
Average number of persons in a Bus/Coach		40													
HDGV traffic (veh/h)		3.75													
Scen:		2		3		4		5		6		7		8	
Proportion of each DG type in the whole for		DG potentially leading to a large (100MN) fire (except liquids)		Propane 50kg		Flammable liquids in bulk (Motor spirit, diesel oil,...)		Fraction of flammable liqs potentially leading to VCE (excl diesel oil)		Chlorine in Bulk		Propane in Bulk		Propane in Bulk	
Ratio:		0.000		0.008		0.363		0.6		0		0.024		0.024	
Remaining part:		0.582													
Period number:		1													
Time ratio for this period		0.25													
		Direction: A+B													
2) Data that are modifiable as a function of the route, the time period and the travel direction															
Route characteristics	Section #	Tunnel? (0=NO, 1=YES)	X (m)	Y (m)	Straight line (m)	User defined length (m)	Urban / Rural?	Rk-DG use?	Total traffic (veh/h)						
	0	0	3250	62450	0	0			0						
	1	0	3300	62300	158	0	Rural	Rk	16						
	2	0	3400	62450	180	0	Rural	Rk	16						
	3	0	3200	61500	971	0	Rural	Rk	16						
	4	0	3700	60120	1468	0	Rural	Rk	16						
	5	0	3520	59520	626	0	Rural	Rk	16						
	6	0	3900	60200	779	0	Rural	Rk	16						
	7	0	4080	60200	180	0	Rural	Rk	16						
	8	0	4100	60450	251	0	Rural	Rk	16						
	9	0	4600	59850	781	0	Rural	Rk	16						
	10	0	5470	59550	920	0	Rural	Rk	16						
	11	0	5400	59300	260	0	Rural	Rk	16						
	12	0	5970	59250	572	0	Rural	Rk	16						
	13	0	6300	59460	391	0	Rural	Rk	87						
	14	0	6350	59320	149	0	Rural	Rk	87						
	15	0	6050	58650	734	0	Rural	Rk	87						
	16	0	6050	58150	500	0	Rural	Rk	87						
	17	0	6500	57550	750	0	Rural	Rk	87						
	18	0	6450	56650	901	0	Rural	Rk	87						
	19	0	6950	57000	610	0	Rural	Rk	87						
	20	0	7250	56800	361	0	Rural	Rk	87						
	21	0	6850	56150	763	0	Rural	Rk	87						
	22	0	6830	54800	1350	0	Rural	Rk	87						
	23	0	6680	54740	162	0	Rural	Rk	87						
	24	0	6600	53700	1043	0	Rural	Rk	87						
	25	0	6150	53000	832	0	Rural	Rk	87						

Figure 6-28 Example of a route definition sheet

When having used the dialogue boxes to define a route for the first time, the user was asked to define a number of periods (up to three) and whether the considered route uses the same itinerary for direction A and direction B.

Once defined those 2 parameters, the user was asked to enter the characteristics of the route for all user-defined periods and/or directions. Those characteristics were stored in the following sheets if relevant:

- **Route_Per1_DirA** for data related to direction A (or directions A and B if direction A and direction B are not distinct) and period 1,
- **Route_Per2_DirA** for data related to direction A (or directions A and B if direction A and direction B are not distinct) and period 2, if at least 2 periods are considered,
- **Route_Per3_DirA** for data related to direction A (or directions A and B if direction A and direction B are not distinct) and period 3, if at least 3 periods are considered,
- **Route_Per1_DirB** to **Route_Per3_DirB** if relevant (i.e. direction B is considered as distinct from direction A, and 1, 2 or 3 periods are considered).

The user can verify what are the sheets used among those 6 sheets by checking cell "C13" in the **Route_Per1_DirA** to **Route_Per3_DirB** sheets. This cell contains time ratio of the considered route if the checked sheet is used or a 0 otherwise.

The user is welcome to modify one or a few parameters in the sheets used among **Route_Per1_DirA** to **Route_Per3_DirB** sheets (this set of sheets will be called Relevant Description Sheets below) once he had enter the characteristics of the route through the dialogue boxes.

The data the user is allowed to modify can be related to a given section of the route or common to all sections.

Data common to all sections that can be modified in the Relevant Description Sheets are the following:

- The average number of persons in a car,
- The average number of persons in a HGV,
- The average number of persons in a Bus/Coach,
- The DG-HGV traffic,
- The proportions of each DG transport in the whole DG traffic,
- The time ratio for each period for direction A sheets (time ratios for direction B cannot be different than for direction A).

Data related to only one section that can be modified in the Relevant Description Sheets are the following:

- Co-ordinates of origin or destination of each section those co-ordinates are to be found in columns "E" and "F" of the Relevant Description Sheets. Those values have to be modified carefully: the origin of the first section and the destination of the last section must be the same on all the Relevant Description Sheets.
- The user defined section length is indicated in column "H" of the Relevant Description Sheets.
- The area where the current is situated: only two items are allowed: "Urban" or "Rural". This parameter is to be found in column "I" of the Relevant Description Sheets.
- The possible use of Rk-DG is indicated in column "J" of the Relevant Description Sheets. If Rk-DG is to be used on the current section, please enter "Rk". In all other cases, enter "Sk". Only those 2 items are allowed in column "J". Those values, have to be modified carefully: it is forbidden to use Rk-DG on tunnel section.
- The total traffic (in veh/h) is indicated in column "K" of the Relevant Description Sheets.
- The HGV ratio is indicated in column "L" of the Relevant Description Sheets.
- The Bus/coaches ratio is indicated in column "M" of the Relevant Description Sheets.
- The car speed (in km/h) is indicated in column "N" of the Relevant Description Sheets.

- The HGV/Bus speed (in km/h) is indicated in column “O” of the Relevant Description Sheets.
- The delay for stopping approaching traffic (in seconds) is indicated in column “P” of the Relevant Description Sheets.
- The number of lanes is indicated in column “Q” of the Relevant Description Sheets. This data has to be modified carefully: if direction A and direction B have been considered to be on the same itinerary when entering (through dialogue boxes) the route for the first time, the number of lanes to consider in the sheets “Ai_Descr” is the number of lanes both for directions A and B. In that case, the number of lanes cannot be lower than 2, and a value greater than 8 is unlikely. On the contrary, if directions A and B have been considered as different (it has been answered “Yes” to the question “Direction A and B described indistinctly” in the dialogue box 1), the number of lanes can be as low as 1, but a value greater than 4 is unlikely.
- The accident yearly frequency (for a HGV to be involved in an accident when going one kilometre) is indicated in column “S” of the Relevant Description Sheets. Such a value can have different origins: either customised or default values.
- A correction factor to the HGV yearly frequencies for DG-HGVs is indicated in column “T” of the Relevant Description Sheets.
- The local density of population (in inhab/km²) is indicated in column “U” of the Relevant Description Sheets. Such a length will be taken into account if Sk-DG is used for the current section.

If the defined route contains one or more tunnels, the user can modify the characteristics of the previously defined tunnels in the **Tunnel1** to **Tunnel3** worksheets. No additional tunnels can be defined at this point.

If some opened sections were first considered through Rk-DG (2D calculations), the user is welcome to modify or re-update the wind rose (**WindRose** sheet), and modify the relevant grids of population (**Pop_Per1** to **Pop_Per3** sheets).

Once all the input data modified by the user, a new calculation can be run without re-running the dialogue boxes. by clicking on the clipart of the “Initial_Inputs” worksheet of the current case.

7. PROGRAM OUTPUTS

7.1 OUTPUTS FROM THE PRE-CONDITIONER

Output from the Pre-Conditioner are exported to Sk-DG.

Contributions to the F/N curves are summed with the open sections contributions.

Damage results

Summary output is sent to Sk-DG in sheets Cost101 to Cost109 (two last digits correspond to tunnel number accordingly to Sk-DG numeration after re-arrangement). The output includes, for each scenario and accident location, the following:

Damage length (m)

tunnel structure

internal civil (structures including roadway)

protected equipment

unprotected equipment

Cost (% of construction capital cost)

tunnel structure

internal civil (structures including roadway)

protected equipment

unprotected equipment

7.2 SK-DG OUTPUTS AND INTERPRETATION

Calculations have been performed for all the selected scenarios and the selected type of calculations (fatalities/injuries, Road users/Local population/Both). The related results are stored in a specific excel file.

Note that the results are related to injuries or fatalities due to the considered dangerous goods itself. Lethality and/or injury due to road accidents are not considered, even if the related expected value can possibly be a lot greater than the one related to the effects of the DGs.

7.2.1 F/N CURVES AND THEIR EXPECTED VALUE (EV)

Several graphs are produced: They show a certain number of F/N curves and corresponding expected values (EVs) are displayed in the Legend if they are not zero and in a subtitle in case, they are zero (because then no corresponding curve is traced):

- **FnCurves_AllScenarii**
- **FnCurves>Loading** in fact, FnCurves_Products would be a better name: the contributions due to the same product (and packaging) are gathered.
- **FnCurve_UserDefined** this graph sums only the contributions of scenarios selected in column K of sheet 'List_Sc'. The summation is realised by formulae and not macro-commands, so a change in sheet 'List_Sc' is immediately transmitted on sheet FnCurve_UserDefined (provided Automatic calculation is 'ON'). The list of scenarios contributing to the calculated EV is displayed in a subtitle.
- **F/N curves for ADR tunnel categories:** There is a curve for each ADR tunnel category (A, B, C, D, E) and a curve displaying all categories.

The use of the 13 scenarios does not allow to make a distinction between categories D and E, and as long it remains so, a unique curve is produced for categories D/E.

These ADR tunnel category curves are produced in every result file even if there is no Tunnel.

7.2.2 INDIVIDUAL RISK INDICATORS

Individual risk indicators produced by Sk-DG are located in sheet **SkRIInd** in a table where risk individual due to every scenario is indicated for 4 different distances for every section (4 columns for direction A and 4 others for B if they are different).

The sections are listed accordingly the internal number resulting from the section re-arrangement operated by Sk-DG if needed (see Step 5 on Figure 5-3), but user section numbers are also indicated. In the last sets of columns on the right side, are realised a summation for all calculated scenarios and a summation for those selected in sheet List_Sc.

Individual risk indicators produced by Sk-DG are located in the sub-directory \Savings\Name Of Relevant Results Sub-Directory\ldexel. The related files are idexel.00i and idexel.res. Those files are ASCII files and can be imported in Excel so as to draw iso-risk contours.

7.2.3 ENVIRONMENTAL RESULTS AND TIME LOST IF TRAFFIC IS DIVERTED

In the results file, two sheets are devoted to these questions. Regarding environmental effects, only qualitative warnings are given.

Regarding traffic diversion, the user can define up to 3 possible alternative routes for diversion, each one being defined by a ratio of diverted traffic, a travel time and a diversion duration.

7.2.4 F/N CURVES AND EXPECTED VALUES INTERPRETATION/COMPARISON

For an absolute purpose, the produced F/N curves and individual risk values can be compared to acceptance criteria. An interpretation resulting from such a comparison should be moderated through uncertainties considerations (see § 7.4 page 71).

When using the QRA model for comparative purposes, the user is facing the question of interpreting two sets of F/N curves, two sets of expected values and/or two sets of iso-risk data. Interpreting those results so as to conclude on the comparison is not easy.

Concerning F/N curves, the first observation to note consists in determining whether or not the two compared curves are intersecting or not. Figure 7-1 below shows an example of intersecting F/N curves, and Figure 7-2 shows an example of non intersecting F/N curves.

If the compared F/N curves are not intersecting, then every lethality level are less frequent in one case. However, if the curves are not very distinct (for example some parts of the compared curves superpose each other) and have expected values of the same order of magnitude (for example, a ratio of 1.5 between 2 expected values generally leads to consider that the expected values cannot be discriminated), a clear distinction between the curves is not possible, and the conclusion is that the compared alternatives cannot be considered as presenting different kinds of risk.

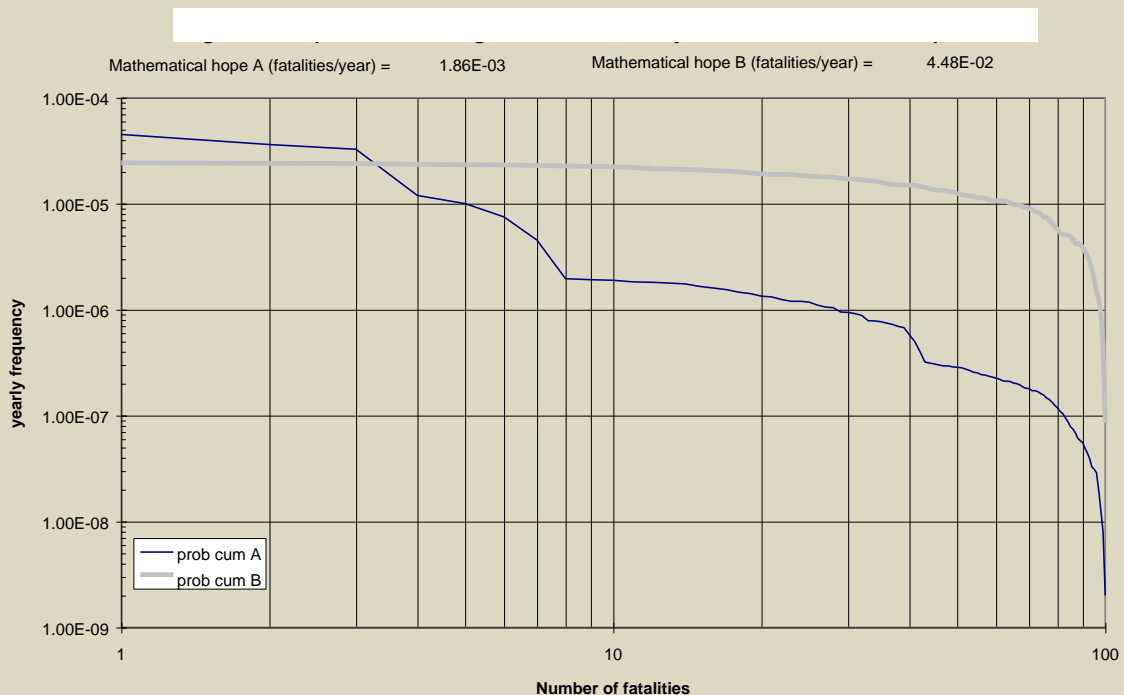


Figure 7-1 Example of intersecting F/N curves with different expected values

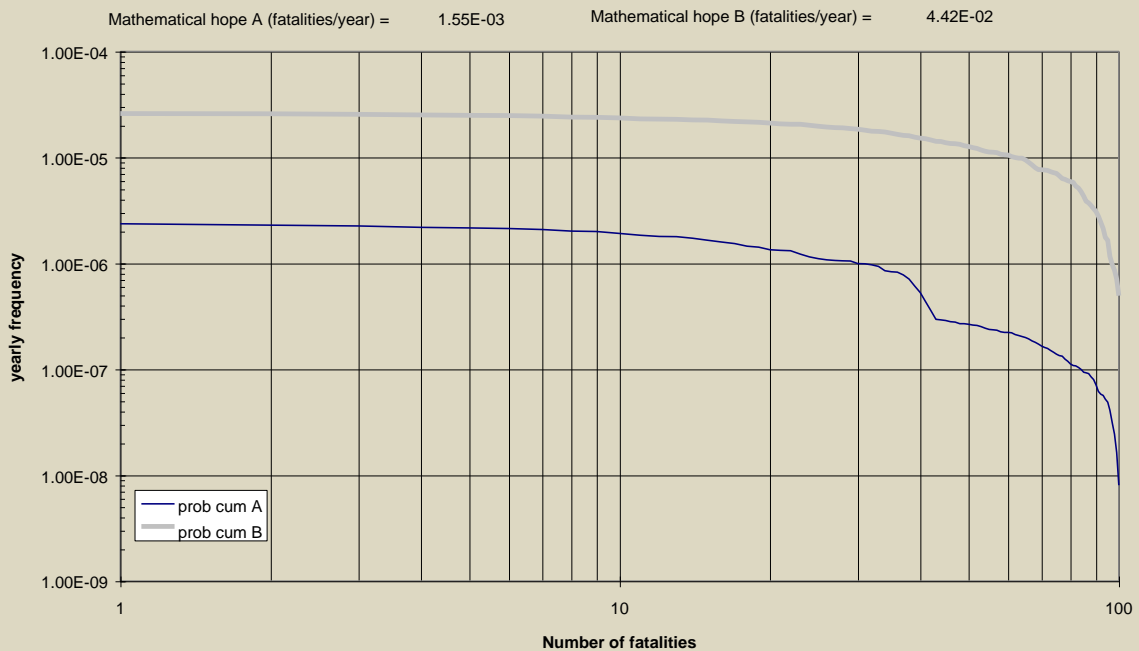


Figure 7-2 Example of non intersecting F/N curves

If the compared curves are intersecting, then several situations can be encountered:

1. One part of the compared curves is very different from one alternative to another and the expected values can be considered as different. Figure 7-1 above illustrates this kind of situation. The two observed curves are intersecting once. The A curve leads to higher frequencies for low lethality, but the A curve and B curve are not sufficiently different on this part (low lethality) to be considered as different. However, for high lethality, the A curve is much less frequent than B curve. The choice of an alternative between A and B has then to be done regarding aversion considerations (it can be considered for example that to get a once a hundred fatalities is more severe than to get a hundred times one fatality).
2. Several parts of the curves are very distinct and the expected values can be considered as different. In that case, one must consider two cases. First case, the distinction between the curves is always in favour of the same curve: then the conclusion is the same as for the preceding point (see point 1. above). Second case, the distinction between the curves is, for some parts in favour of the A curve and in some case in favour of the B curve. Then, the conclusion has to be pondered regarding the expected values and aversion considerations.
3. The curves are intersecting and the expected values cannot be considered as different. In that case, the conclusion is generally that the 2 alternatives do not lead to risks of different nature.

7.3 RK-DG OUTPUTS AND INTERPRETATION

7.3.1 F/N CURVES AND THEIR EXPECTED VALUE (EV)

F/N curves produced by Rk-DG have been exported to Sk-DG and are examined simultaneously with the rest of the contribution as explained in § 6.2.1 page 30.

7.3.2 2D INDIVIDUAL RISK INDICATORS

2D iso-risk contours are stored in files **idexel.00i** where i is the number of the scenario during the execution. These files are lists of numbers separated by commas which represent the individual risk on the nodes of a grid. This grid corresponds with the one with which the population densities have been entered. Abscissas of every node appear on a line flanking the upper part of the table, Ordinate of the nodes appear in a column flanking the table on its right side. This table may be easily opened by Excel (delimited by commas or of .csv type).

Obviously, the results contained in the idexel.00i files are only related to the route sections for which the user has indicated in the Sk-DG dialogue boxes that a 2D calculation would be performed.

7.4 UNCERTAINTY/SENSITIVITY OF RESULTS

7.4.1 GENERAL CONSIDERATIONS

The first point to mention is that the risk due to dangerous goods transport is assessed in the QRA model by mean of simplifications that are related to the method itself:

- 5 types of dangerous goods/conditioning were chosen for their representativeness of the whole DG traffic that is likely to generate different levels of consequences to people and the environment. This number seems very low compared to the hundreds of different dangerous goods and/or conditioning that are encountered on the road.
- 8 scenarios were derived from those 5 types of dangerous goods/conditioning.

At the same time, traffics related to a whole class or a part of a class of dangerous goods are applied to each of the previously selected goods/conditioning so as to be able to deal with full structure of dangerous goods transport.

Simplifications are a necessity regarding the complexity of a real case.

The methodological simplifications used to build the QRA model were introduced so as to make the project feasible and also to stick as much as possible to the effective situation of the transport goods by roads. Those methodological simplifications induce inherent approximations that contribute to uncertainties at a basic level. Those uncertainties are obviously difficult to measure.

However, uncertainties are also to be found at another level, especially concerning the probability assessment and the consequence modelling.

As for probabilities, the work carried out by IRR (see **reference manual**) showed that uncertainties range from 250 % to 400 % with a 95 % confidence interval.

Concerning the consequence aspects, one can consider that the uncertainties are of the same order of magnitude.

This point illustrates how important it is to use best estimates at a local scale: custom local data are always preferable to default values, based on national averages.

Apart from the uncertainty estimate, a sensitivity analysis was carried out on input data required by the QRA model so as to highlight how the model reacts to key parameters variations. The results of the corresponding parameterised study are proposed in the next paragraph.

7.4.2 RESULTS OF A PARAMETERISED STUDY ON SK-DG

The results of this parameterised study are developed in annex 1 below. The objective of this parameterised study is to explore the way some modifications of input parameters affect the output results obtained with Sk-DG for open air sections.

All the results of this parameterised study lead to logical conclusion according to theoretical expectations.

8. GUIDANCE FOR SPLITTING ROUTE INTO SECTIONS

Once again, a tunnel is considered for Sk as a unique section.

Splitting a route into section is simple in a majority of cases, but it may become very complex if strategies are explored: different routes for different periods.

To treat these cases, it is important to have a clear understanding of:

- what may happen for road users when an accident occurs,
- what happens in Sk-DG and what is its re-arrangement procedure.

8.1 CONCEPT OF SEPARATED DIRECTIONS, ITS IMPLICATION FOR ROAD USERS

When an accident occurs in one direction, the model considers always that all lanes in this direction are closed to the traffic. Traffic flows freely from this point downstream. But a traffic jam develops upstream and grows with time (until the upstream closing of the road takes effect).

Now, for the other direction, it is crucial to explore 2 questions:

- Does the accident stop the traffic?
- May the road users be among the victims of the scenario?

If directions A and B are not described separately, the model will consider that the traffic is stopped in the other direction and its road users are potential victims (Figure 8-1).

If directions A and B are described separately, and section coordinates are nearly, (see RefManual § 10.3.2) equal, the model will consider that the traffic is not stopped in the other direction but its road users are potential victims (Figure 8-2).

If directions A and B are described separately, and section coordinates are sufficiently (see RefManual § 10.3.2) different, the model will consider that the traffic is not stopped in the other direction and its road users cannot be harmed (Figure 8-3).

This holds good for open air sections and tunnel sections.

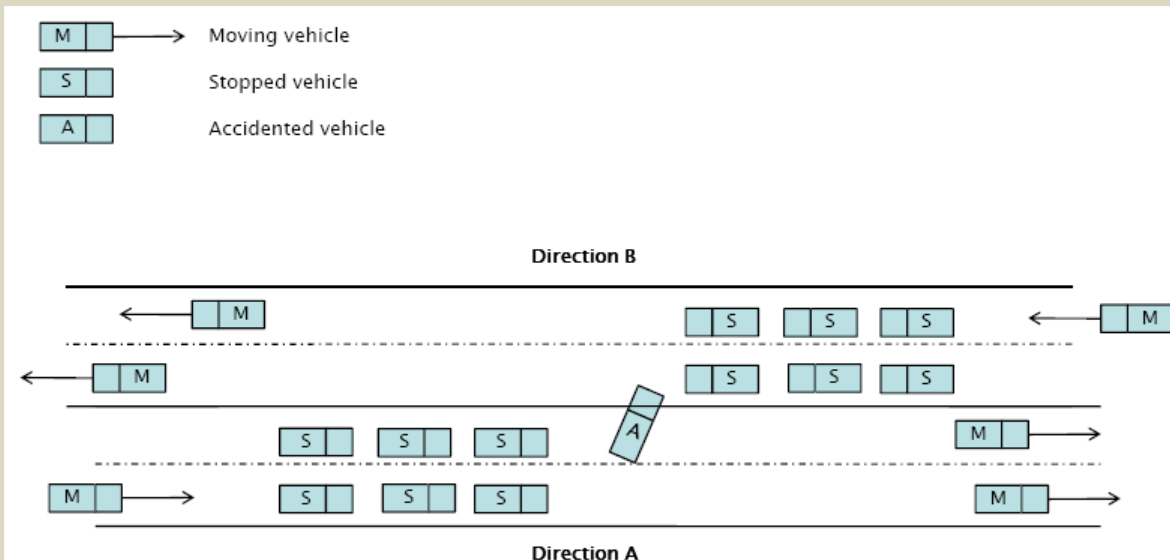


Figure 8-1 Directions A and B described indistinctly

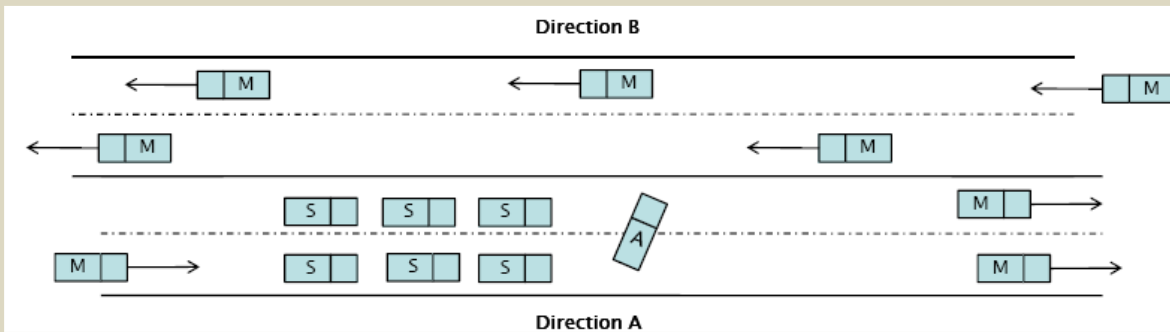


Figure 8-2 Directions A and B described separately, same section coordinates

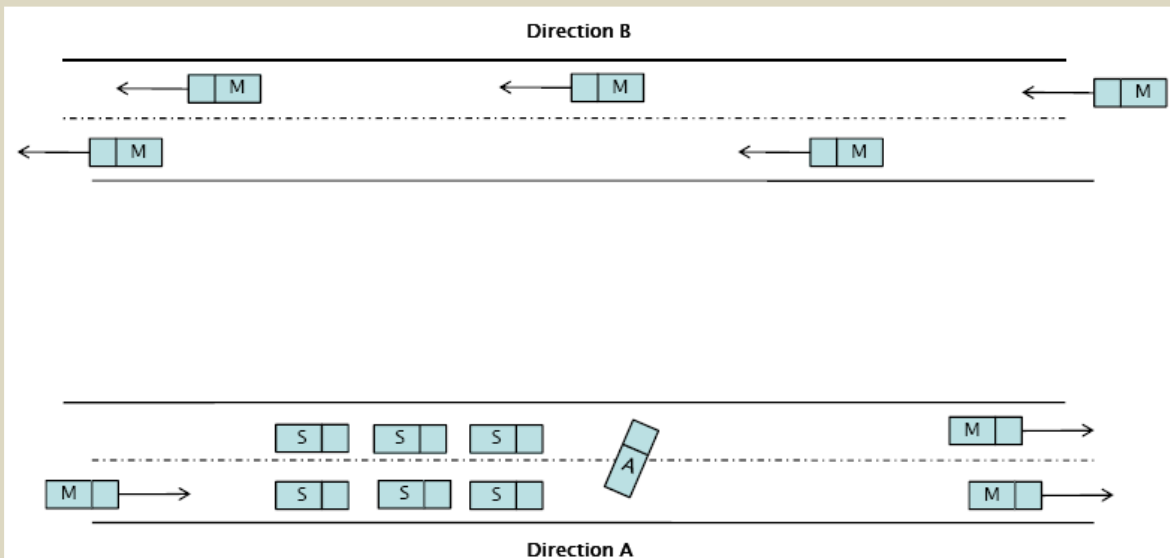


Figure 8-3 Directions A and B described separately, different section coordinates

8.2 RULES

The route descriptions take the form of lists of sections which have either the type “open air section” or the type “tunnel section”. Every section has direction A parameters and direction B parameters which may differ (length_A different from length_B for example).

Because of the way the software Sk-DG has been written, the following rules must be observed.

1. A section has always 2 directions (which may be described separately or not).
2. For a given section (section number N), the type (open or tunnel) is the same for both directions. But a section may for instance be for:
 - period 1 « Open Air » with a 1D computation,
 - period 2 « Open Air » with a 2D computation,
 - period 3 « Tunnel.
3. For a given period, on the whole section length, direction A parameters must be homogeneous (same applies for direction B). [It means that traffic and its composition, density of surrounding populations may be considered as homogeneous (uniform over the whole length)]. We refer to this rule as “homogeneity criterion”.

Thus, for a given period, the description of a “one way” portion of route cannot be performed independently of the description operated for the other direction.

It would be very difficult for the user to respect these rules if the dialog boxes did not take them into account. But they do. For instance, when a parameter must be the same for both directions, the user has to enter its value when filling the dialog box relative to direction A. But when the same box is displayed for direction B, the parameter is stuck and can no longer be changed.

The same applies for parameters that have to be chosen for period 1, but must remain unchanged for periods 2 and 3. They are stuck when the dialog boxes relative to those periods are displayed.

8.3 DESIGNING SECTIONS FOR AN OPEN AIR ROUTE

Whatever the software (Risk-DG or Sk-DG) used, the route to be computed must be split into segments and these segments correspond to sections for Sk-DG.

The definitions and rules given here-above guide the user to make the correct splitting in simple cases. The splitting is easy when there is a unique open route used for every time period in direction A and direction B (Figure 8-4) because user defined segments become automatically Sk-DG sections.

If a few segments are “one way segments”, the description may become trickier.

A “natural splitting” operated only on the homogeneity criterion leads to NA segments for direction A and NB segments for direction B.

If $NA = NB$ (like in Figure 8-5), there is no problem a Sk-DG section is obtained by “collocating” 2 user defined segments (section 3 correspond to segment 3A and segment 3B).

If $NB > NA$ like in Figure 8-6, it is possible to add $(NB-NA)$ null length segments (Figure 8-7). We call this the “collocating procedure”.

8.4 PRESENCE OF TUNNELS

Different sorts of tunnel exist:

- one bore tunnel for both directions,
- one bore tunnel for one direction,
- two bores tunnel.

Because of rule 2, for Sk-DG software, a tunnel is simultaneously present on both directions.

Figure 8-8 presents a case with a two bores tunnel where the bores do not have the same length. This is not a problem for Sk-DG software since for every type of section (open and tunnel) different lengths may be entered for direction A and direction B.

Figure 8-9 presents a case with a one bore tunnel in one direction (B). The other direction (A) is entirely in the open. This case is exactly similar to the one in Figure 8-8, except that a null length is given to the false tunnel segment in direction A.

Figure 8-10 presents a more complex case and the additional null length segments which are needed to enable the “collocating procedure”.

In conclusion, when dealing with a route, a “collocating procedure” of the segments created in each direction accordingly to the homogeneity criterion (rule 3) is needed so as to ensure that rules 1 and 2 are also satisfied.

8.5 INFLUENCE OF ROUTE VARYING WITH TIME PERIODS

If one considers 3 periods (Normal, Quiet and Peak) and 2 directions (A and B). If routes differ with the periods and directions A and B, the situation may become very complex.

There are theoretically 6 patterns: NA, NB, QA, QB, PA, PB.

Sk-DG has been designed so as to work with this complexity in every case (once both sides of the same section for the same period are of the same type)

But it may do it more or less clumsily.

Sk-DG has a loop on section numbers and once this section number is chosen, it asks for the characteristics of the segments for all periods and directions.

If for one given section number, the segments declared are geographically similar on both directions for all time periods, then and only then will it make calculations only once for them.

USER	Normal				Peak			
	A		B		A		B	
	Geometry	Traffic	Geometry	Traffic	Geometry	Traffic	Geometry	Traffic
1	1A N	Real	1B N	Real	1A P	Real	1A P	Real
2	2A N	Real	2B N	Real	2A P	Real	2A P	Real
3	3A N	Real	3B N	Real	3A P	Real	3A P	Real
4	4A N	Real	4B N	Real	4A P	Real	4A P	Real

Table 8-1 Input by users in case of a splitting like shown by alternative 1 of Figure 8-11

For the peak period, the use may split the routes as shown in alternative 1 of Figure 8-11. He will then enter the routes as shown in Table 8-1 above. The software Sk-DG will accordingly re-arrange the sections as appears in Table 8-2 below.

Sk-DG	Normal				Peak				
	A		B		A		B		
	Geometry	Traffic	Geometry	Traffic	Geometry	Traffic	Geometry	Traffic	
1	1A N	Real	1B N	Real	1A P	Real	1A P	Real	Geometrically similar
2	2A N	Real	2B N	Real	Null length	0	Null length	0	
3	Null length	0	Null length	0	2A P	Real	2A P	Real	
4	3A N	Real	3B N	Real	Null length	0	Null length	0	
5	Null length	0	Null length	0	3A P	Real	3A P	Real	
6	4A N	Real	4B N	Real	4A P	Real	4A P	Real	Geometrically similar

Table 8-2 Re-arrangement by Sk-DG in case of a splitting like shown by alternative 1 of Figure 8-11

USER	Normal				Peak			
	A		B		A		B	
Section #	Geometry	Traffic	Geometry	Traffic	Geometry	Traffic	Geometry	Traffic
1	1A_N	Real	1B_N	Real	1A_P	Real	1A_P	Real
2	2A_N	Real	2B_N	Real	2A_P	Real	2A_P	Real
3	3A_N	Real	3B_N	Real				
4	4A_N	Real	4B_N	Real				

Table 8-3: Input by users in case of a splitting like shown by alternative 2 of Figure 8-11

For the peak period, the user may split the routes as shown in alternative 2 of Figure 8-11. He will then enter the routes as shown in Table 8-3 above. The software Rk-DG will accordingly re-arrange the sections as appears in Table 8-4 below.

Sk-DG	Normal				Peak			
	A		B		A		B	
Section #	Geometry	Traffic	Geometry	Traffic	Geometry	Traffic	Geometry	Traffic
1	1A_N	Real	1B_N	Real	Null length	0	Null length	0
2	Null length	0	Null length	0	1A_P	Real	1A_P	Real
3	2A_N	Real	2B_N	Real	Null length	0	Null length	0
4	Null length	0	Null length	0	2A_P	Real	2A_P	Real
5	3A_N	Real	3B_N	Real	Null length	0	Null length	0
6	4A_N	Real	4B_N	Real	Null length	0	Null length	0

Table 8-4: Re-arrangement by Sk-DG in case of a splitting like shown by alternative 2 of Figure 8-11

In this case, the result is the same and both alternatives seem equivalent. In fact alternative 1 is very superior, because, if route does not stop in Z but goes 20 more sections further, with alternative 1, these sections will be in concordance and correspond to only one section for Sk (26 sections for Sk in total). With alternative 2, they won't be in concordance (and the result will be 46 sections for Sk !).

So this concordance is essential to get a faster and more efficient work of Sk-DG.

8.6 PRACTICAL CONSEQUENCES WHEN ENTERING SECTIONS

For each period build sections satisfying homogeneity criterion and with matched type in the A and B directions.

Try to make a concordance so that Sk-DG might have a maximum number of sections geometrically similar on both sides for all periods.

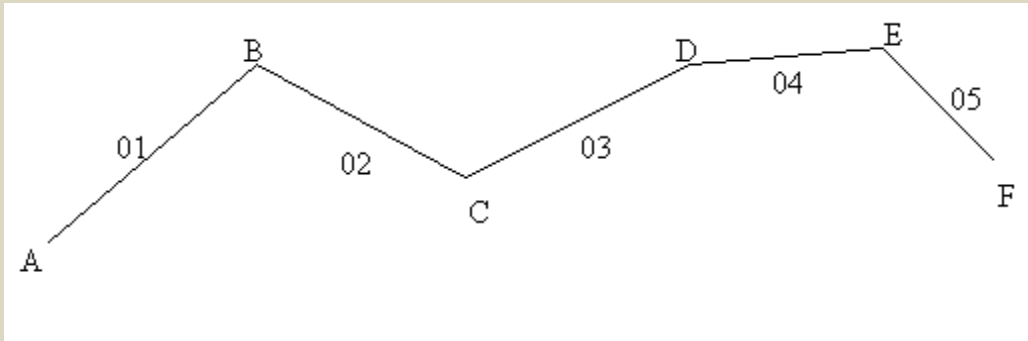


Figure 8-4 Route from A to F (direction A) and F to A (direction B). The 5 sections are represented by 2 digits numbers.

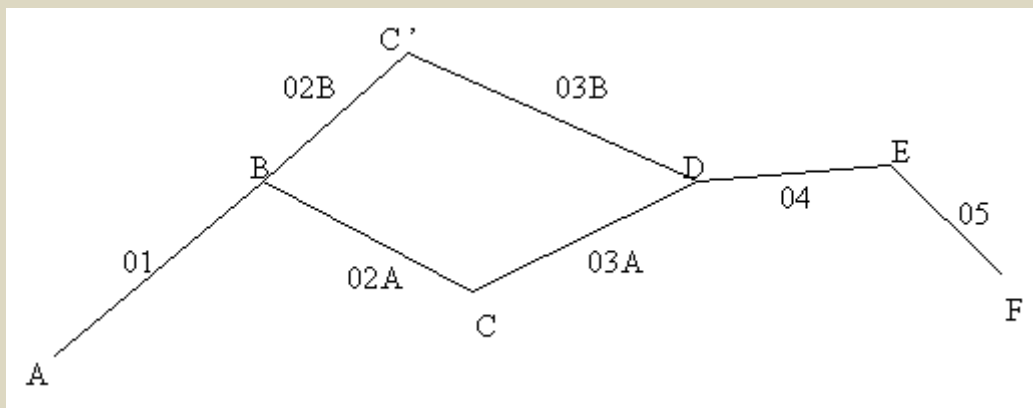


Figure 8-5 Route A C F (direction A) and F C ' A (direction B).

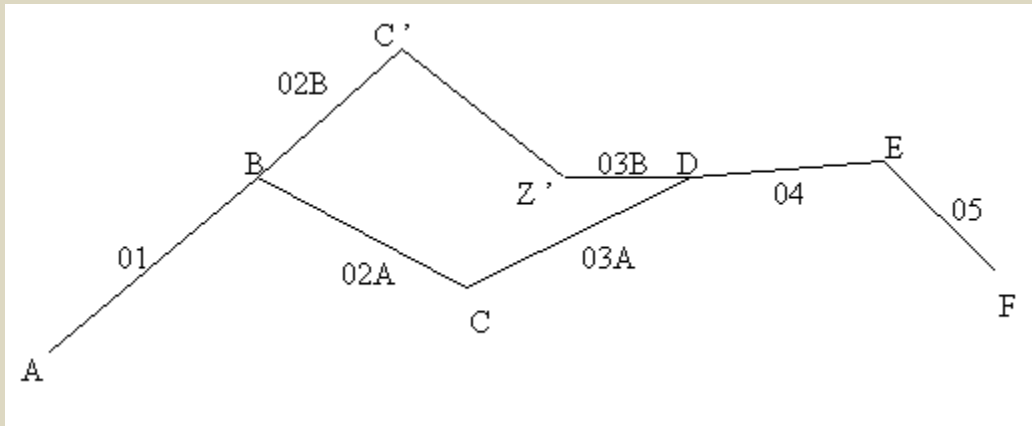


Figure 8-6 Route A C F (direction A) and F Z ' C ' A (direction B).

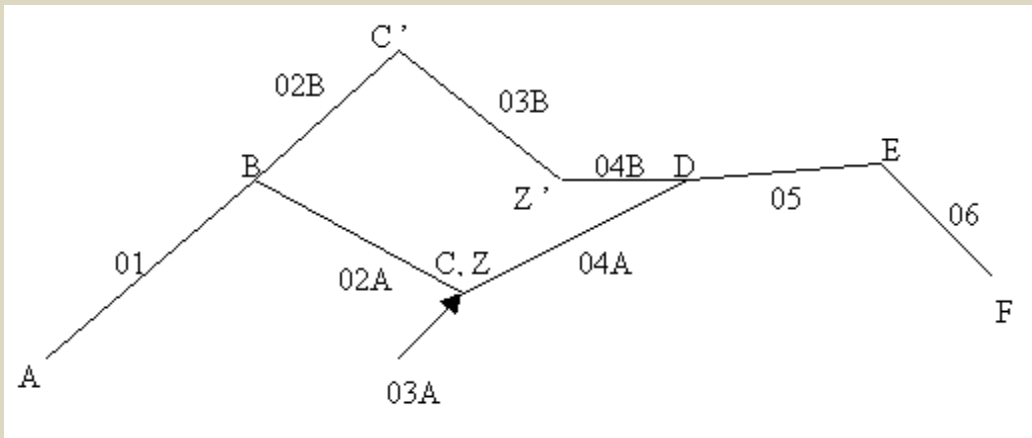


Figure 8-7 Route A (C Z) F (direction A) and F Z ' C ' A (direction B). Points C and Z are at the same location. Section 03A has a null length.

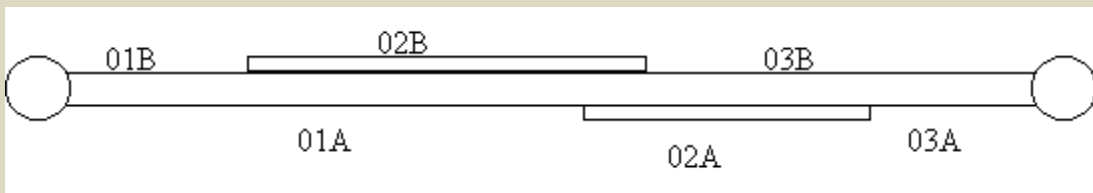


Figure 8-8 Accounting for the presence of a two bore tunnel on a route where bores in directions A and B do not have the same length.

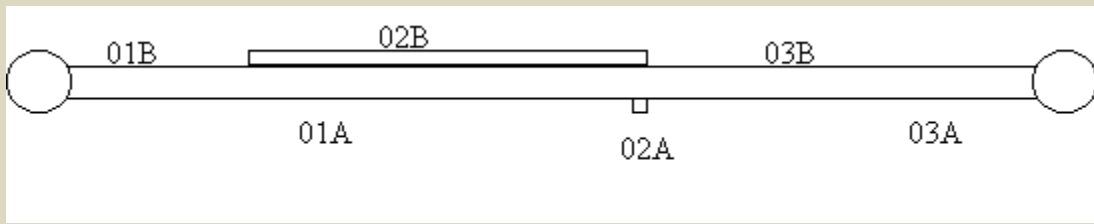


Figure 8-9 Accounting for the presence of a one bore tunnel on a route. Physically there is only one segment in direction A (we suppose there is homogeneity on its whole length). A tunnel null length segment is added in direction A. It splits in 2 parts the initial segment present in direction A. After this splitting and creation there are finally 3 segments in direction A. Their types are matched with those of corresponding segments on the B side: the collocating procedure is satisfied.

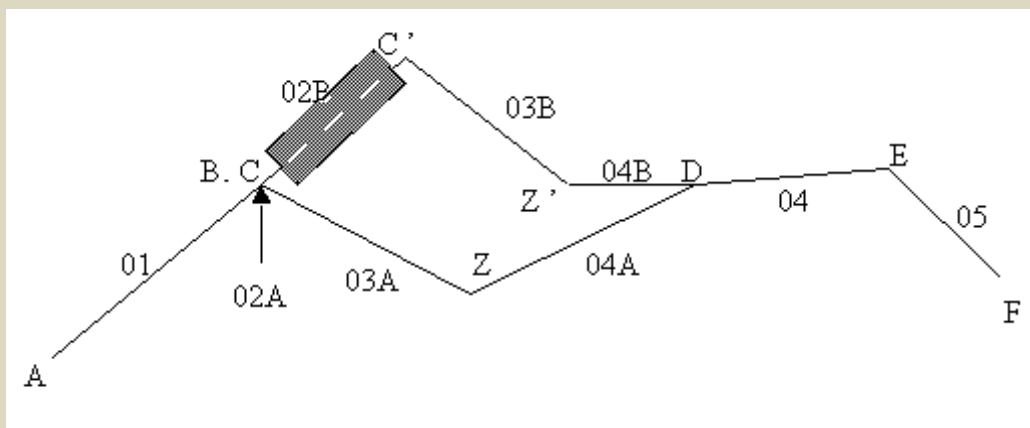


Figure 8-10 Accounting for the presence of a tunnel on a route where directions A and B do not correspond. The tunnel (02B in direction B) is associated with a null length tunnel section (02A in direction A).

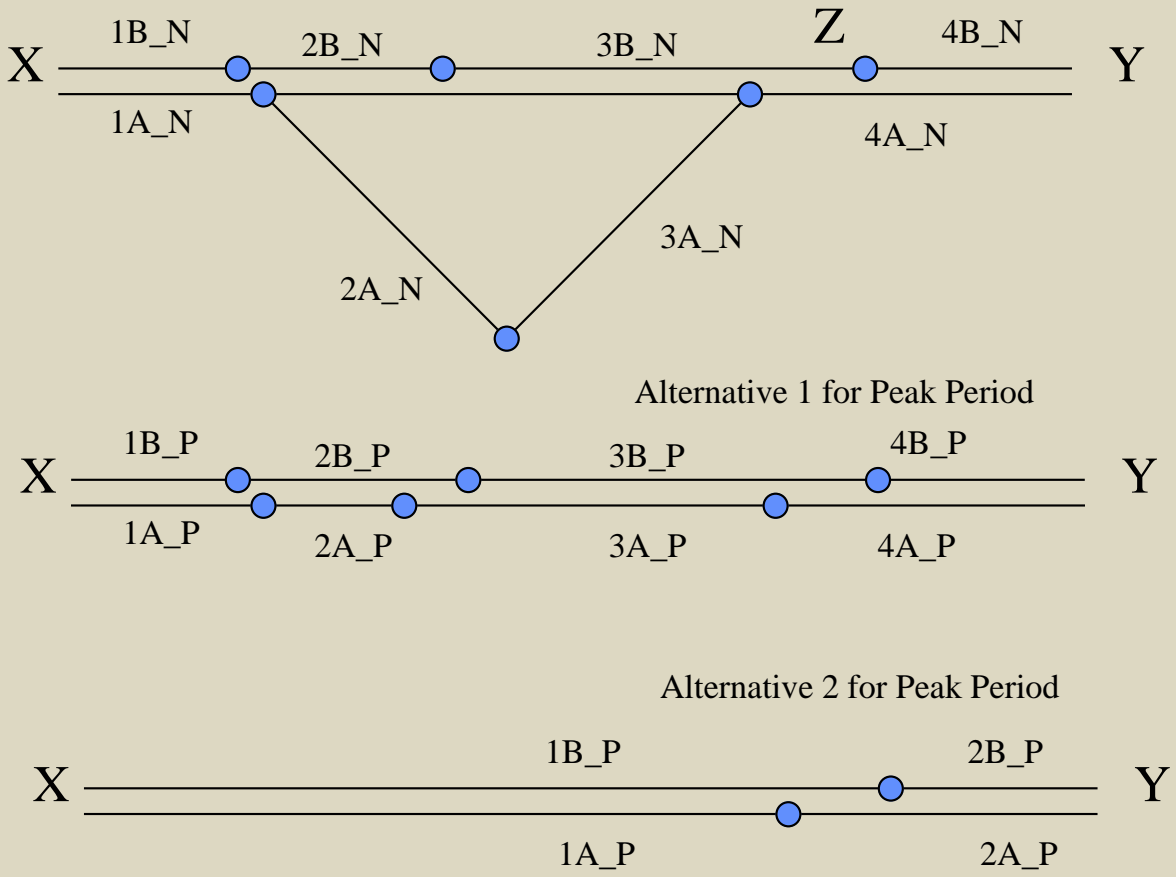


Figure 8-11 A road between X and Y loses its homogeneity in direction B in location Z. It may be taken freely in both direction in Peak period. During Normal period, in direction A, traffic is diverted. So, during normal period, direction A needs at least a 4 segment definition (and so does also direction B).

9. GUIDANCE FOR DESCRIBING TUNNEL SECTIONS

This chapter aims at providing the user with guidance so as to describe a tunnel and its characteristics in the QRA model.

Basically, three types of tunnel are considered below:

- a one direction single bore tunnel with longitudinal ventilation system,
- a twin bores tunnel, one direction per bore and longitudinal ventilation,
- a bi-directional single bore tunnel with semi-transverse ventilation system.

Examples are given for each type of tunnel.

9.1 ONE DIRECTION SINGLE BORE TUNNEL WITH LONGITUDINAL VENTILATION SYSTEM

This paragraph is devoted to the description of the case of a route that encloses a tunnel in direction A and is completely in the open in the opposite direction (direction B).

Figure 9-1 below illustrates how the user must describe such a situation in the QRA model:

- To the question: “Are direction A and B symmetrical?” (dialogue box number 1) the user must answer “No”.
- To the query “enter the number of sections” (dialogue box number 2),
 - the user must enter N+1 if the route is made of N sections. That is, for a route made for example of:
 - one open air section,
 - then the tunnel section in direction A (and another open air section in direction B),
 - and finally an open air section,
 - the user must describe the following:
 - An open air section as section 1, corresponding to the first open air section,
 - A tunnel section as section 2, with a null length tunnel in direction B; this section is used to described the tunnel section in direction A,
 - An open air section as section 3, with a null length in direction A; this section is used to described the median open air section in direction B,
 - An open air section as section 4, corresponding to the last open air section.

When the journey is geographically very different in direction B from what it is for the tunnel section in direction A, the user has the possibility to describe the open air zone in direction B corresponding to the tunnel section in direction A as several sections. In such a case, the user must add as many null length sections in direction A as needed (see also chapter 8).

When defining the route, the user is asked to enter a “Delay for stopping approaching traffic”. This delay has a priori to be defined with taking into account another parameter, the “time taken to activate emergency ventilation”. Indeed, in case of a tunnel with a control centre, both actions (if possible and envisaged in case of an emergency) are likely to be made used simultaneously.

However, in some other situations, it could be possible to activate an emergency ventilation system without forbidding access to the dangerous zone (because there is no possibility to do so) or conversely it could be possible to forbid access to the dangerous zone (for example on open air highway sections with tolls) without initiating any ventilation device.

In case it is possible simultaneously to activate the emergency ventilation system and to forbid access to the dangerous zone, the user must keep in mind that:

- Between the action of giving an order or pushing a button from a control centre and the reality “on the field”, a supplementary delay can exist. It always exists for ventilation: a few minutes after having started the fans are necessary to have full efficiency from the fans. Regarding the act of forbidding access to the dangerous zone, 2 types of situations are a priori possible:
 - access is forbidden by mean of gates; in such a case, the time taken between the order and its effective achievement is very short,
 - access is forbidden by operators with vehicles and signs; in such a case, the time taken between the order and its effective achievement can be much longer.
- The above mentioned supplementary delays must be taken into account in any case in the value entered by the user.

If there is no possibility to forbid access to the dangerous zone, the user must enter a high value as a “Delay for stopping approaching traffic”, **for example 9 000 seconds**. Indeed, the way this delay is used in the QRA is the following (see also **paragraph 10.3** of the **Reference Manual** for further details):

- For each scenario and on each section, this delay is compared to the delay between accident and scenario, which is function of the scenario and the type of environment (open air or tunnel). Typically, the delay between accident and scenario is considered as lasting a few minutes;
- The traffic is supposed to continue to reach the dangerous zone (upstream) or to run away from this zone (downstream) during the minimum value (t_{min}) of the “delay for stopping approaching traffic” and the “delay between accident and scenario”: a traffic jam is considered to grow upstream while vehicles evacuate downstream;
- The number of victims is calculated on the basis of the situation when this minimum value t_{min} is reached.

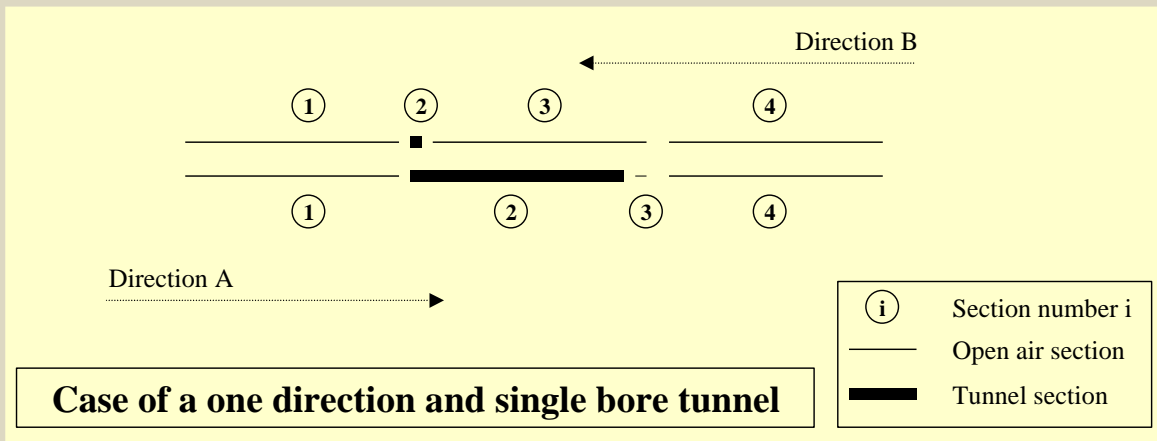


Figure 9-1 Example of a route with a tunnel in direction A and no tunnel in direction B. The figure illustrates how the user must describe it in the QRA model

Once the route is described the way above, the user is asked to describe only one tunnel (the one in direction A), the null length tunnel in direction B being automatically dropped by the QRA model.

Figure 9-2 below gives an example of input data for the tunnel characteristics. Those data must be determined carefully. In particular, Normal ventilation, time taken to activate ventilation and emergency ventilation situations have to be carefully studied before entering values in the QRA model.

For new tunnels, ventilation studies generally exist. The related results can be used to get the input data for the pre-conditioner.

For old tunnels, if no study is available, there are two possibilities:

- the user has longitudinal ventilation calculation tools at hand and therefore can use them to define the normal and emergency ventilation regimes;
- the user has no such calculation tools at hand.

In the latter, the user can for example refer to a software named TUNVEN delivered by NTIS (US National Technical Information Services). This publicly available DOS program “solves the coupled one dimensional steady state tunnel aerodynamics and advection equations to obtain the air velocities and pollutant concentrations for a given tunnel design, traffic load and ventilation rate”. It could have been obtained at the following web address: <http://www.ntis.gov/fcpc>, with use of the following keywords: “Ventilation” and “Tunnel”. Its price was \$112 for North America and \$224 everywhere else.

In any case, the user must pay attention to the specificity of the tunnel to be described. In a one direction and single bore tunnel, the normal ventilation is made of the following:

- the piston effect due to traffic,
- the air movements due to meteorology (wind effect at portals and gradient of temperature between the atmosphere inside the tunnel and outside),
- when needed, the use of fans to limit the traffic induced pollution.

If not obtained by mean of past studies or software of the public domain, the normal ventilation description can be obtained:

- through records, if data from an anemometer installed in the studied tunnel are available;
- with the help of simple formulas.

A possibility to calculate the average contribution of the piston effect to the normal ventilation consists in calculating separately the air speeds generated by the traffic during the different periods of time and in averaging those values through the time ratios of those periods. The calculation of air speed can be achieved by using the equations described in Annex 3 of the present User's guide.

The contribution of the meteorology (wind speed, temperature gradient) can also be calculated with help of simple formulas as the following:

$$\Delta P = P_{dyn} * \left(\alpha + \lambda * \frac{L_{bore}}{Dh_{bore}} \right)$$

where:

- ΔP is the pressure gradient (Pa) between portals due to meteorological conditions,
- P_{dyn} is the dynamic air pressure (Pa): $P_{dyn} = \frac{1}{2} * \rho_{air} * v_{air}^2$ (about 6 Pa for 3 m/s),
- α is a singular pressure loss coefficient at tunnel portals,
- λ is the tunnel surface average roughness,
- Dh_{bore} is the tunnel equivalent diameter (m): $Dh_{bore} = \frac{4 * S_{bore}}{P_{bore}}$,
- S_{bore} is the section (m²) of the considered tunnel,
- P_{bore} is the tunnel perimeter (m).

Then the contribution of jets fans - if present and likely to be activated (to reduce the concentration of pollutants in the tunnel) - must be added. The typical function modes in a normal situation are part of the tunnel description: for example, the fans are designed to blow X m³/s, and, when the first level of pollution is detected, the fans are activated to Y % of their capacity. The tunnel records should then provide the information on the time ratios when the first, second... levels of pollution are exceeded.

All those contributions can lead to significant high average air velocity in a single direction tunnel. However, after the accident has occurred, a traffic jam grows upstream and the traffic decreases downstream, the result of which is a decrease of the piston effect.

Then 3 types of situations can be envisaged:

- Emergency ventilation is likely to be put in action within a few minutes,
- No emergency ventilation is likely to be put in action,
- Emergency ventilation is likely to be put in action after a relatively long time.

Tunnel 1 inputs							
	symbol	units	data				
cross-section geometry							
effective width	W	m	15.25				
effective height	H	m	5.1				
open cross-sectional area	A	m ²	77.775				
camber	Cam	%	2.5				
lengthwise geometry							
...segments (homogeneous - ventilation, gradient)							
total number of segments	Ns	-	4				
segment number	-	-	1	2	3	4	
segment lengths	Xs	m	1110.210385	315	335	260	
total length of tunnel	Xt	m	2020.210385				
segment gradient	Gs	%	0	0.5	-0.5	0.5	
...nodes (segment start and end points)							
total number of nodes	Nn	-	5				
node number	-	-	1	2	3	4	5
location of node	Xn	m	0	1110.2104	1425.2104	1760.2104	2020.2104
ventilation - normal							
...segments							
segment number	-	-	1	2	3	4	
volume flow rate extracted from tunnel	VsN	m ³ /s	0	0	0	0	
...nodes (segment start and end points)							
node number	-	-	1	2	3	4	5
volume flow rate along tunnel at nodes	VnN	m ³ /s	275	275	275	275	275
ventilation - emergency							
number of emergency ventilation regimes	nE	-	1				
time taken to activate emergency ventilation	tE	mins	1 Warning: This value can differ as a function of period even if the tunnel is the same for all periods				
segment number	-	-	1	2	3	4	
emergency ventilation regime if accident within this segment	iE	-	1	1	1	1	
...volume flow rate extracted from tunnel							
segment number	-	-	1	2	3	4	
emergency ventilation regime	1	-	0	0	0	0	
...volume flow rate along tunnel							
node number	-	-	1	2	3	4	5
emergency ventilation regime	1	-	234	234	234	234	234
drainage							
open area of discrete drains or continuous slot (per Xd m)	Ad	m ²	0.3				
interval between drains, or slot length used to define Ad	Xd	m	100				
traffic							
traffic direction (0=bi-directional, 1=A-to-B, -1=B-to-A)	TrDir	-	1				
traffic density (0=none, 1=light, 2=normal, 3=peak)	TrDen	-	1.02759				
mitigation measures							
average spacing between emergency exits	Xe	m	100				
emergency coms (0=no, 1=bell/siren, 2=PA, 3=PA+CCTV)	Ecom	-	3				

Figure 9-2 Example of input data for a one bore unidirectional tunnel

In the first case, the user should then enter:

- the calculated normal ventilation (in the example above, 275 m³/s all along the tunnel) for a typical situation before the accident (with moving traffic, meteorological effects and possible use of fans for cleaning air purposes),
- the “time taken to activate emergency ventilation”, with taking into account the time to have emergency ventilation fully efficient in the entered value (1 minute to take the decision + 4 minutes to have the fans fully activated in the example above),
- the theoretical emergency ventilation (in the example above, 234 m³/s whatever is the accident location in the tunnel). This emergency ventilation is defined by the way the emergency ventilation system has been designed: for example, to avoid as far as possible backlayering in case of a fire, a air velocity not lower than 3 m/s can be guaranteed by construction when all the fans are put in action.

In the second case, to stick as far as possible to what happens, the user can describe the situation and its evolution with entering:

- the calculated normal ventilation (in the example above, 275 m³/s all along the tunnel) for a typical situation before the accident (with moving traffic, meteorological effects and possible use of fans for cleaning air purposes),
- a delay that takes account of the time to reach the situation when traffic is stopped, and the scenario is developed,
- the ventilation situation after traffic is topped (for cases similar to the example above, the air flow rate could fall to only a few cubic meters per second (or even could be reversed) if no emergency ventilation is activated.

In the last case, the user could take account of the long delay before activating the emergency ventilation with entering:

- a “normal” ventilation that is an average between the typical situation before the accident and the deteriorated situation when the emergency ventilation is put in action (consequently, in the example above, the value to enter as “normal” ventilation should be lower than 275 m³/s, and, as a function of the case, it could not be sufficient to avoid backlayering),
- the “time taken to activate emergency ventilation”, with taking into account the time to have emergency ventilation fully efficient in the entered value (for example, 11 minute to take the decision + 4 minutes to have the fans fully activated in the example above),
- the theoretical emergency ventilation (in the example above, 234 m³/s whatever is the accident location in the tunnel). This emergency ventilation is defined by the way the emergency ventilation system has been designed: for example, to avoid as far as possible backlayering in case of a fire, a air velocity not lower than 3 m/s can be guaranteed by construction when all the fans are put in action.

9.2 TWIN BORE TUNNEL, ONE DIRECTION PER BORE AND LONGITUDINAL VENTILATION

This paragraph is devoted to the description of the case of a route that encloses a two bores tunnel, with one bore per direction.

Figure 9-3 below illustrates how the user must describe such a situation in the QRA model:

- To the question: “Are direction A and B symmetrical?” (dialogue box number 1) the user must answer “No”.
- To the query “enter the number of sections” (dialogue box number 2), the user must enter N+2 if the route is made of N sections. That is, for a route made for example of:
 - one open air section,
 - then the tunnel section (one bore per direction),
 - and finally an open air section,
 - the user must describe the following:
 - An open air section as **section 1**, corresponding to the first open air section,
 - A tunnel section as **section 2**, with a null length tunnel in direction B; this section is used to described the tunnel section in direction A,
 - An open air section as **section 3**, with a null length in direction A and B; this section won't be used by the QRA. It just allows to consider separately the 2 bores of the tunnel,
 - A tunnel section as **section 4**, with a null length tunnel in direction A; this section is used to described the tunnel section in direction B,
 - An open air section as **section 5**, corresponding to the last open air section.

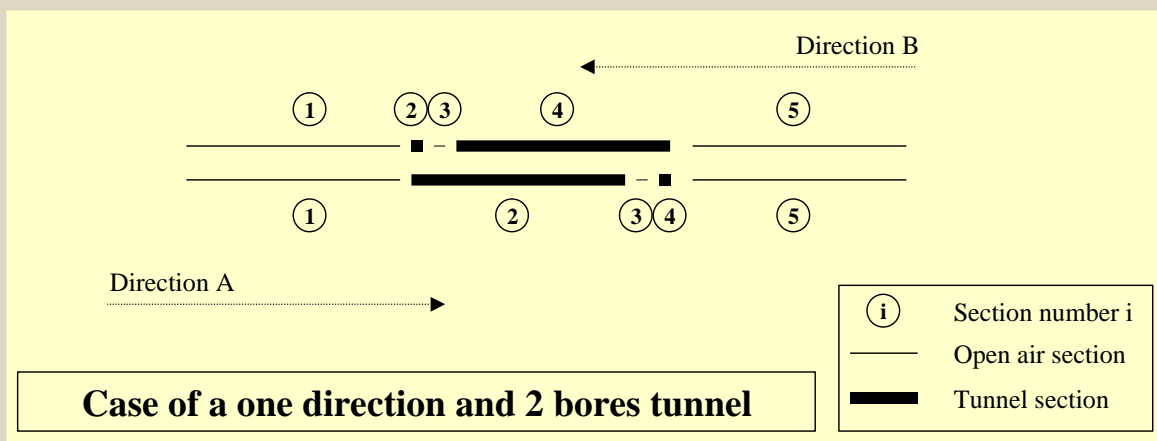


Figure 9-3 Example of a route with a twin bores tunnel (one per direction). The figure illustrates how the user must describe it in the QRA model

Once the route is described the way above, the user is asked to describe successively 2 tunnels (one for direction A and one for direction B), the null length tunnel and open air sections being automatically dropped by the QRA model.

To enter the characteristics of the bore in direction A, one can refer to section 9.1. The characteristics of the bore in direction B can be determined similarly to the ones in direction A, except that the user must pay attention to the sign used: whatever is the direction considered, the tunnel is described the same way: from section N-1 to section N+1.

In other words, it must be considered that the first segment (tunnel sub-section) described for tunnel in direction A is also the first segment described for tunnel in direction B, but this segment is:

- the first tunnel segment reached by the road users if they drive in direction A,
- the last tunnel segment reached by the road users if they drive in direction B.

The considered direction is automatically signalled by the QRA to the user in cell D72 of the tunnel description sheets, and:

- If the value in cell D72 is "1", then the description of the tunnel must be performed in the same way than the traffic direction (direction A bore).
- If the value in cell D72 is "-1", then the description of the tunnel must be performed in the opposite way than the traffic direction (direction B bore).

Practically:

- it is not generally necessary to invert the gradient signs of the tunnel segment for the direction B bore (except if on a given segment, road users of the two bores are going up - respectively. down - at the same time; i.e. if gradient is inverted from one direction to another);
- on the contrary, it is necessary to invert the air flow rate signs so that the air is blown in the same direction than traffic.

As a summary, Figure 9-4 below gives an example of input data for the tunnel characteristics in direction B.

Tunnel 2 inputs				symbol	units	data				
cross-section geometry										
effective width	W	m	15.65							
effective height	H	m	5.1							
open cross-sectional area	A	m ²	79.815							
camber	Cam	%	2.5							
lengthwise geometry										
...segments (homogeneous - ventilation, gradient)										
total number of segments	Ns	-	4							
segment number	-	-	1	2	3	4				
segment lengths	Xs	m	1110.210385	315	335	260				
total length of tunnel	Xt	m	2020.210385							
segment gradient	Gs	%	0	0.5	-0.5	0.5				
...nodes (segment start and end points)										
total number of nodes	Nn	-	5							
node number	-	-	1	2	3	4	5			
location of node	Xn	m	0	1110.2104	1425.2104	1760.2104	2020.2104			
ventilation - normal										
...segments										
segment number	-	-	1	2	3	4				
volume flow rate extracted from tunnel	VsN	m ³ /s	0	0	0	0				
...nodes (segment start and end points)										
node number	-	-	1	2	3	4	5			
volume flow rate along tunnel at nodes	VnN	m ³ /s	-250	-250	-250	-250	-250			
ventilation - emergency										
number of emergency ventilation regimes	nE	-	1							
time taken to activate emergency ventilation	tE	mins	1	Warning: This value can differ as a function of period even if the tunnel is the same for all periods						
segment number	-	-	1	2	3	4				
emergency ventilation regime if accident within this segment	iE	-	1	1	1	1				
...volume flow rate extracted from tunnel										
segment number	-	-	1	2	3	4				
emergency ventilation regime	1	-	0	0	0	0				
...volume flow rate along tunnel										
node number	-	-	1	2	3	4	5			
emergency ventilation regime	1	-	-240	-240	-240	-240	-240			
drainage										
open area of discrete drains or continuous slot (per Xd m)	Ad	m ²	0.3							
interval between drains, or slot length used to define Ad	Xd	m	100							
traffic										
traffic direction (0=bi-directional, 1=A-to-B, -1=B-to-A)	TrDir	-	-1							
traffic density (0=none, 1=light, 2=normal, 3=peak)	TrDen	-	1.02759							
mitigation measures										
average spacing between emergency exits	Xe	m	100							
emergency coms (0=no, 1=bell/siren, 2=PA, 3=PA+CCTV)	Ecom	-	3							

Figure 9-4 Example of input data for the direction B bore of a twin bore tunnel

9.3 BI-DIRECTIONAL SINGLE BORE TUNNEL AND SEMI-TRANSVERSE VENTILATION

This paragraph is devoted to the description of the case of a route that encloses a bi-directional single bore tunnel.

Figure 9-5 below illustrates how the user must describe such a situation in the QRA model:

- To the question: “Are direction A and B symmetrical?” (dialogue box number 1) the user has the possibility to answer “Yes” if on other sections direction A and B are not separated, as it is for this tunnel section.
- To the query “enter the number of sections” (dialogue box number 2), the user just has to enter N if the route is made of N sections. That is, for a route made for example of:

- one open air section,
- then the tunnel section,
- and finally an open air section,

the user must describe the following:

- An open air section as **section 1**, corresponding to the first open air section,
- A tunnel section as **section 2**,
- An open air section as **section 3**, corresponding to the last open air section.

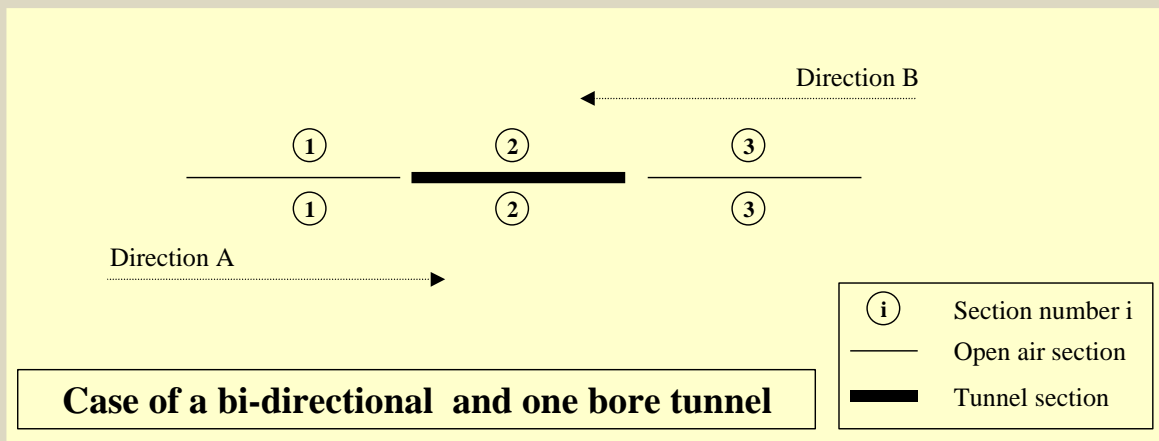


Figure 9-5 Example of a route single bore bi-directional tunnel. The figure illustrates how the user must describe it in the QRA model

Once the route is described the way above, the user is asked to describe 1 tunnel (one for directions A and B).

Figure 9-6 below gives an example of input data for the characteristics of a single bore bi-directional tunnel.

Tunnel 1 inputs				symbol	units	data								
cross-section geometry														
effective width	W	m	10.5											
effective height	H	m	4.55											
open cross-sectional area	A	m ²	47.775											
camber	Cam	%	2											
lengthwise geometry														
...segments (homogeneous - ventilation, gradient)														
total number of segments	Ns	-	7											
segment number				1	2	3	4	5	6	7				
segment lengths	Xs	m	1425	1424	1157.5	1157.5	1146	1146	1146	1146				
total length of tunnel	Xt	m	8602											
segment gradient	Gs	%	1.65	1.65	1.65	1.65	-0.5	-0.5	-0.5					
...nodes (segment start and end points)														
total number of nodes	Nn	-	8											
node number				1	2	3	4	5	6	7	8			
location of node	Xn	m	0	1425	2849	4006.5	5164	6310	7456	8602				
ventilation - normal														
...segments														
segment number				1	2	3	4	5	6	7				
volume flow rate extracted from tunnel	VsN	m ³ /s	0	0	0	0	0	0	0	0				
...nodes (segment start and end points)														
node number				1	2	3	4	5	6	7	8			
volume flow rate along tunnel at nodes	VnN	m ³ /s	1.8	29.1	56.4	79.8	103.2	124.8	146.4	168				
ventilation - emergency														
number of emergency ventilation regimes	nE	-	7											
time taken to activate emergency ventilation	tE	mins	5	Warning: This value can differ as a function of period even if the tunnel is the same for all periods										
segment number				1	2	3	4	5	6	7				
emergency ventilation regime if accident within this segment	iE	-	1	2	3	4	5	6	7					
...volume flow rate extracted from tunnel														
segment number				1	2	3	4	5	6	7				
emergency ventilation regime			110	0	0	0	0	0	0	0				
			0	110	0	0	0	0	0	0				
			0	0	110	0	0	0	0	0				
			0	0	0	110	0	0	0	0				
			0	0	0	0	110	0	0	0				
			0	0	0	0	0	110	0	0				
			0	0	0	0	0	0	110	0				
			0	0	0	0	0	0	0	110				
			0	0	0	0	0	0	0	0	110			
...volume flow rate along tunnel														
node number				1	2	3	4	5	6	7	8			
emergency ventilation regime			108.2	25.5	52.8	76.2	99.6	121.2	142.8	164.4				
			91.8	119.1	36.4	59.8	83.2	104.8	126.4	148				
			81.5	108.8	136.1	49.5	72.9	94.5	116.1	137.7				
			64.9	92.2	119.5	142.9	56.3	77.9	99.5	121.1				
			50.5	77.8	105.1	128.5	151.9	63.5	85.1	106.7				
			34.4	61.7	89	112.4	135.8	157.4	69	90.6				
			16.9	44.2	71.5	94.9	118.3	139.9	161.5	73.1				
drainage														
open area of discrete drains or continuous slot (per Xd m)	Ad	m ²	0.09											
interval between drains, or slot length used to define Ad	Xd	m	1											
traffic														
traffic direction (0=bi-directional, 1=A-to-B, -1=B-to-A)	TrDir	-	0											
traffic density (0=none, 1=light, 2=normal, 3=peak)	TrDen	-	1.416570667											
mitigation measures														
average spacing between emergency exits	Xe	m	200											
emergency coms (0=no, 1=bell/siren, 2=PA, 3=PA+CCTV)	Ecom	-	3											

Figure 9-6 Example of input data for a single bore bi-directional tunnel

In a bi-directional tunnel, the ventilation system is generally of a transverse type. In such situations, the ventilation system is generally organised in independent ventilation-sections, which need to be described. In the example above, the segments have been defined according to the ventilation scheme below (see Figure 9-7):

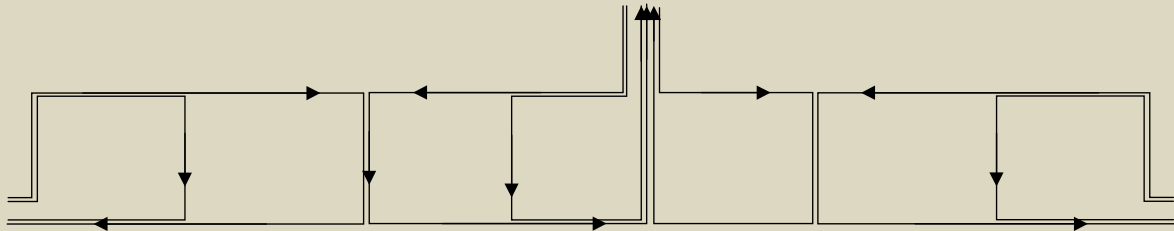


Figure 9-7 Principle of the ventilation organisation in the considered example

Thus, 7 segments have been defined, one per ventilation-section. Between 4th and 5th segment, the gradient is inverted.

Regarding the normal ventilation:

- the piston effect has been neglected (same traffic in directions A and B),
- the effect of meteorology has been taken into account by applying a 80 Pa pressure gradient, which was taken as representative of an average wind pressure added to possible gradients of temperature between inside and outside of a long tunnel in winter times in a mountainous area.
- no extraction has been considered.
- fresh air has been considered to be blown all along the tunnel with 30 % of the maximal capacity (for pollution purposes).

Note that, on Figure 9-6 above, the line devoted to “Extraction” in normal ventilation situation is put to 0, whereas the line devoted to “volume flow rate along tunnel at nodes” takes account for meteorological effects plus fresh air flows all along the tunnel.

In case of an emergency, it was considered that, apart from the meteorological effects and fresh air flows, an extraction was put in action. This extraction is located around the accident place. Consequently, it was defined as many emergency ventilation regimes as there are segments defined: if, for example an accident occurs in segment number 3, 110 m³/s have been considered to be extracted in segment number 3, and nothing is extracted in the other segments (see Figure 9-6 above). In the lines devoted to “volume flow rate along tunnel at nodes” in case of an emergency, an assessment was made of the cumulated effects of meteorology + fresh air flows (that were supposed to be continued after the emergency ventilation is put in action) + extraction in the relevant segment.

Note that once the flow rate calculated at one point (given the initial conditions), the calculations of the flow rate at node N+1 is very simple:

$$F_{N+1} = F_N + E_N + B_N$$

Where B_N is the flow of fresh air blown in segment N, E_N is the flow extracted in segment N and F_N is the flow at node N.

9.4 REPRESENTATION OF LONG TUNNELS WITH DISCRETE SMOKE EXTRACTION ZONES

Some tunnels with ceiling exhaust ducts are sub-divided along their length into separate exhaust zones of order 200-300 m in length. In the event of a fire, dampers are opened in the vicinity of the fire and closed elsewhere to allow smoke to be extracted from as close to the fire as possible. With a long tunnel, there could be a large number of possible emergency ventilation regimes since there will be as many regimes as there are separate exhaust zones in the tunnel. Currently, the tunnel consequence model only allows 10 separate zones to be defined.

But it is important to note that the hazard calculations are carried out for only five representative locations (basically 17%, 33%, 50%, 67% and 85%) along the tunnel length. Emergency ventilation regimes therefore only need to be specified for these five incident locations. The exhaust ventilation description may be achieved by specifying 11 zones, as illustrated in Figure 9-8. Zones 2, 4, 6, 8 and 10 correspond to the zones where extraction is performed when the fire is located successively at each one of the 5 locations (basically 17%, 33%, 50%, 67% and 85%). In order to allow this, in Version 3.60, the maximum number of segments which was previously 10 has been increased to 15 when a new case is entered.

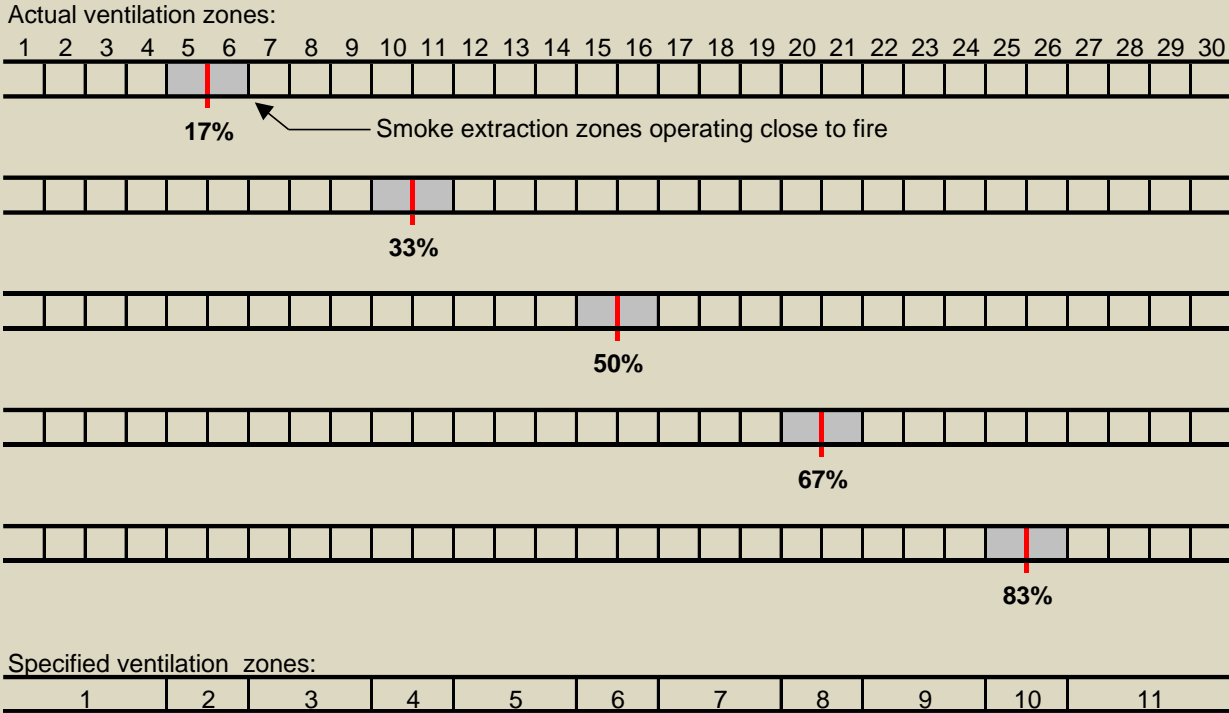


Figure 9-8 Example illustrating selection of ventilation zones

10. CALIBRATION AGAINST AN OBSERVED LEVEL OF RISK

This work was undertaken in addition to the contract. It aims at comparing results given by the QRA model with a global level of risk due to the transport of dangerous goods on routes.

This comparison has been possible only for surface routes: in tunnels, there are too few accidents involving dangerous goods to build reference data. And it was undertaken for France only.

The structure of this chapter is organised as follows:

- Determination of an observed level of risk of reference,
- Description of the calculations performed with the QRA model,
- Comparison and interpretation of results.

10.1 DETERMINATION OF AN OBSERVED LEVEL OF RISK OF REFERENCE

From the French MTMD database (data from years 1993, 1995, 1996 and part of 1997 have been scanned), it appears that in France, in average each year, about 2 accident involving dangerous good transports are leading to fatalities directly due to the dangerous good itself. As a comparison, it can be noted that the database contains approximately 200 recordings per year.

For year 1996, SITRAM (Système d'Information sur les Transports de Marchandises) published statistics summarising the transport of dangerous goods in France and expressed it in tonnes * kilometres. This amount is approximately $8 \cdot 10^9$ tonnes * kilometres

If one considers an average HGV capacity of 15 tonnes per vehicle fully loaded (see paragraph 4.4 of appendix 1 of the reference manual), the number of vehicles * kilometres for year 1996 can be approximated as $1.1 \cdot 10^9$ vehicles * kilometres (this amount assumes that the average load effectively transported by a DG-HGV is approximately half of the total capacity of the vehicle).

From those data, one can consider that the dangerous goods cause:

$$1.9 \cdot 10^{-9} \text{ fatalities / (year * vehicle * kilometre)}$$

10.2 DESCRIPTION OF THE CALCULATIONS PERFORMED WITH THE QRA MODEL

A first calculation was undertaken for an open air single section route of one kilometre with the following conditions (average conditions for France):

- Taking into account of scenarios 3, 4, 5, 7, 8, 9 10 (scenarios 1 and 2, that are not related to DG transport, were skipped, as well as scenario 6 since chlorine is not transported by road in large bulks in France),
- Consideration of DG types distribution according to French averages,
- 100 inhabitants per square kilometre (average value in France),
- 600 vehicles of all kind per hour (this average data and the following were estimated from statistics available at the following address www.urf.asso.fr),
- a ratio of HGV in the whole traffic of 5 %,
- a ratio of bus / coaches in the whole traffic of 1%,
- average speeds about 60 km/h,
- French default accident rates (both for HGVs and DG-HGVs).

It can be a priori considered that such an approach using only average values could lead to a biased estimation of the level of risk, because:

- the repartition of population is not at all uniform (there are large areas in France where there is nobody and where there is no route);
- threshold effects may possibly appear. This can be illustrated by an artificial example. If on one hand one considers a scenario that leads to calculate 0.9 victim (0.2 victim among road users and 0.7 among population) if describing population density as an average 100 inhabitants per square kilometres, the associated expected value is null because of a threshold at 1 victim when summing up the expected values. If on the other hand one considers that the population density is no longer uniform but null along half of the route and equal to 200 inhabitants per square kilometres along the other half, the scenario produces 1.6 victims on the second half and the associated expected value is no longer null.

So discrepancies in the results are a priori possible due to the fact that the route is described with more or less details. However, it is to note that discrepancies due to a threshold effect could be minimised by lowering the limit for the representation of the consequences (that is one fatality).

Such possible discrepancies led us to undertake a second calculation. In that case, the route is composed of three sections, each one being supposed as representative of one type of road/environment:

- The first section was supposed to be representative of a motorway in a rural area. The average traffic was considered as being about 1200 vehicles per hour, with a HGV ratio of 18 %, 2 lanes per direction, and an average density of population of 100 inhabitants per square kilometre.
- The second section was supposed to be representative of a national road in a rural area. The average traffic was considered as being about 350 vehicles per hour, with a HGV ratio of 5 %, 1 lane per direction, and an average density of population of 100 inhabitants per square kilometre.
- The last section was supposed to be representative of a urban area. The average traffic was considered as being about 625 vehicles per hour, with a HGV ratio of 5 %, 1.5 lane per direction as an average, and an average density of population of 5000 inhabitants per square kilometre.

Then it is to define the relative lengths to attribute to each of the three sections. From statistics, one learns that:

- The total traffic in France on motorways is approximately $90 \cdot 10^9$ vehicle *kilometre a year,
- The total traffic in France on rural routes (except motorways) is approximately $282 \cdot 10^9$ vehicle *kilometre a year.
- The total traffic in France routes situated in a urban area is approximately $132 \cdot 10^9$ vehicle *kilometre a year.

So we attributed the following length distribution to the 3 sections:

- 900 m to the first section,
- 2820 m to the second section,
- 1320 m to the last section.

10.3 COMPARISON AND INTERPRETATION OF RESULTS

The first calculation (the one with one section) leads to calculate a global level of risk of:

$$1.2 \cdot 10^{-10} \text{ fatalities / (year * vehicle * kilometre)}$$

This number is one order of magnitude under the calculation of reference.

The second calculation (the one with three sections) leads to calculate a global level of risk of:

$$1.4 \cdot 10^{-9} \text{ fatalities / (year * vehicle * kilometre)}$$

This number is of the same order of magnitude than the calculation of reference.

If one performs the same two calculations with a lower limit at 0.1 (instead of 1) for representing the consequences, the results are the following:

- The first calculation leads to $6 \cdot 10^{-10}$ fatalities/(year*vehicle*kilometre),
- The second calculation leads to $1.5 \cdot 10^{-9}$ fatalities/(year*vehicle*kilometre).

From such an exercise, several conclusions emerge:

- The comparison reinforces the work performed by the QRA model: the results of the second calculation are of the same order of magnitude than the observed one. However, comparisons of this kind should be performed for other countries, or for each class of dangerous goods if data available. Besides, it would be necessary to perform the same work for tunnels, but there are too few data to do so.
- Those results underline the great influence of the description on the final result: an average description of the route could lead to underestimate the global level of risk.
- An averaging description of the route leads to emphasise the threshold effect described above. On the contrary, the description of the route in three sub-sections is not sensible to a variation of the lower limit of the consequences description.
- At last, it is to note that even the second calculation (the one with three sections) does not take into account the discrepancies in the traffic as a function of time (peak, normal or quiet periods). So the results of the second calculation are to consider a priori as a minimum value. As an example (this time the value are not issued from statistics because we do not have sufficient data to do so), we considered the same 3 sections with different traffics and populations for 3 different periods of time, and calculated a global level of risk of:

$$1.7 \cdot 10^{-9} \text{ fatalities / (year * vehicle * kilometre)}$$

11. APPENDICES LIST

Annex	Designation	Number of pages
1	Parameterised Sensitivity Study for Software Sk-DG	11
2	Parameterised Sensitivity Study for Tunnel Pre-Conditioner	10
3	Piston effect in a tunnel	2
4	Preparing data sets	5
5	How to choose DG traffic rates	4
6	General procedure for the installation and its testing	3
7	How to use the installation executable file	5
8	ADR combination tool	4
9	Additional Information & user advice	12
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ANNEX 1

Parameterised Sensitivity Study for Software Sk-DG

1. Scope

The objective is to explore the way some modifications of input parameters affect the output results obtained with Sk-DG for open air sections.

These output results are mainly:

- Expected Values resulting from the integration of F/N curves
- Individual Risk indicators at different distances from the routes.

The contribution to the Expected Values comes partly from victims among road users and partly from victims among local populations.

The Individual Risk concerns only local populations. It is independent of the density of population.

2. Approach used for the Parameterised Sensitivity Study

To realise the Parameterised Sensitivity Study, the following approach has been devised and used:

- choose a basic contribution related to a single open air section defined by its own parameter (section 1 in table 1),
- duplicate this section 15 other time and have at each time only one (or sometimes 2 parameters if they are very similar) changed,
- compare the results with the basic output.

This has been done 3 times:

- with only road users,
- with only local population,
- with simultaneously road users and local population.

Tables 2 to 4 give the corresponding results for the expected value variations. In table 5, the sum of the separate calculations among road users and local population is compared with the output of a simultaneous computation.

Concerning Individual Risk, since it is independent of road users and population density, only one set of result is given (table 6).

We have also explored the influence of parameters such as :

- a very short delay between accident and scenario (tables 7 and 8),
- meteorological wind speed distribution (Tables 9 and 10 with sea meteorology),
- forty people per bus/coach instead of 25 as in basic calculations of tables 2 and 4.

3. Interpretation of findings

Variations of input parameters create variations in output results which are very logical and in accordance with theoretical expectations.

These logical findings are listed in table A. Explanations are given below for results showing in this table that might appear as surprising.

Explanation 1:

If global traffic is 10 times more important,

- fluid traffic will be 10 times denser (10 times more people on 1 km),
- a traffic jam will grow 10 times faster.

But, if during time between accident and scenario, even the less denser traffic is sufficient to create a traffic jam long enough so as to reach the limits of the zone endangered by the scenario, the global traffic density will have no influence. If time between accident and scenario equals zero, the number of victims is proportional to the global traffic as long as the phenomenon described below in explanation 2 remains negligible. This has been checked in an additional calculation (scenarios 6, 7 and 8 in table 7).

Explanation 2:

When population density is multiplied by 10, number of victims is multiplied by 10. But if a scenario produces 0.452 fatalities at a certain location for certain circumstances (and corresponding yearly frequency), its contribution to the Expected Value will be nought because, it has been decided to discard contributions for less than 1 fatality. If for exactly the same location and circumstances (and thus the same yearly frequency), population is 10 times denser, the number of fatalities will be 4.52 (rounded to 4). Corresponding contribution to the expected value is no longer nought. Ratio between the two computations will be higher than 10.

This rounding does not concern Individual Risk.

In table 5, it appears that Expectation Values are higher for a simultaneous computation of victims among road users and local population than for the sum of two separate computations. This is due to the phenomenon described just above in Explanation 2.

All calculations presented in tables 1 to 6 were performed with the delays between accident and scenario showing in table 11. Tables 7 and 8 are related to computations achieved with no delay between accident and scenario. It was suspected this parameter might have an important influence on victims among road users. And it is effectively true : Table 8 shows great discrepancies with table 2.

All calculations presented in tables 1 to 6 were performed with the reference meteorology showing in table 13. Tables 9 and 10 are related to the « sea » meteorology [This meteorology is one of the meteorological sets proposed in the ExpertUser Interface]. Table 9 shows discrepancies with table 4 only for scenarios affected by the meteorology, scenario 5 (VCE of motor spirit), scenario 6 (release of chlorine) , scenario 8 (VCE of LPG in bulk) and scenario 10 (release of ammonia).

All results obtained show that the change of Urban to Rural which implies a change in the protection distribution as shown in table 14 does not play any significant role on the number of victims (provided that their densities remain unchanged) or on Individual Risk for local populations (table 6).

No calculation has been performed so as to explore what would be the variations induced by a change in the probability of occurrence of the scenarios shown in table 12. It is obvious the Expectation Values and Individual Risk would be proportional to these parameters as long as no phenomenon as the one described in Explanation 2 above does not intrude.

If the number of people in every bus/coach is changed from 25 to 40, the global Expected Value (for Road Users and Local population for 10 scenarios) is increased from 25.E-06 to 30.E-06 fatalities per year (+20 %).

4. Conclusions

All findings are qualitatively in logical accordance with theoretical expectations.

In certain cases, the multiplying ratio may be quantitatively predicted (effect of length). but these cases are very few, because, for example, as far as road users are concerned different time delays lead to a greater or lesser influence of the trapping in traffic jams. This trapping influence is different for short range and long range scenarios. It may lead sometimes to output variations that may seem strange or even erroneous. We gave 2 examples of explanations for such oddities.

According to time delays and the type of scenarios considered, sensitivity factor may be very different. For instance with a 300 seconds time delay for stopping approaching traffic, the conclusion is that global traffic has no importance for short or medium range delayed scenarios (long delay between accident and scenario manifestation). Nevertheless this parameter is generally crucial.

Understanding of the influence is already not easy when they are modified one after the other and that road users and local populations are dealt separately. The global influence of each parameter simultaneously on road users and local populations is very complex to predict.

The global influence of all parameters simultaneously, simultaneously on road users and local populations is awfully complex to predict.

If an input parameter of influence is easy to assess with a good precision (length of the sections for instance), its contribution to the global errors on Expected Values and Individual Risk will remain limited.

Problems come mainly from input parameters of influence which are difficult to evaluate correctly.

For scenarios 3 to 10,

Both, expected values and Individual Risk are proportional (in fact it is not exactly true for EVs, because, changes in the traffic composition may change the density of road users present in a certain length of fluid traffic or traffic jam) to the following mathematical product :

[traffic accident frequency rate for HGVs * Correction factor DG-HGV/HGV * Conditional probability of occurrence of the scenario (table 12) * DG-HGVs traffic * traffic ratio among DG-HGVs for considered DG]

The Expected Value is also :

- partly proportional to the number of people present in a « mean vehicle » multiplied by the global traffic
- partly proportional to the population density.

For scenarios 1 and 2,

Individual Risk is proportional to the product :

[traffic accident frequency rate for HGVs * Conditional probability of occurrence of the scenario (table 12) * Global traffic * HGV traffic ratio among all vehicles]

The Expected Value is proportional to this product also but in the same time,

- partly proportional to the number of people present in a « mean vehicle » multiplied by the global traffic
- partly proportional to the population density.

So, if one considers Global traffic, Expected Value depends on this parameter affected by an exponent which should range between 1 (small traffic, dense population) and 2 (intense traffic, light population density).

It is very difficult to announce orders of magnitude of the errors that will be made. But, if Expected Value for scenarios 1 and 2 is proportional to Global traffic at power 1.8, an error of 80 % is theoretically likely to be reached (if all other input parameters are perfectly chosen) if a day is considered as a single period (see table B). In fact, the risk to have this error is not important for Open Air sections, because, numbers of victims due to scenarios 1 and 2 are very small there. It is much more important in tunnel sections.

Period	Time ratio	Actual Global traffic (veh/h)	Actual contribution to EV
Normal	0.25	1000	62797
Peak	0.125	2000	109336
Quiet	0.625	200	8664
Day	1	625	107791

Table B Example showing that in case when Expected Values are proportional to Global traffic at power 1.8, the treatment of the day as a unique period leads to an error of 80 % for contributions of scenarios 1 and 2. This is very theoretical for Open Air sections because there, these scenarios produce very small numbers of victims and a treatment of the day as one uniform period might lead to less than 1 victim (EV = 0).

	Road Users only	Local Population only
Length*10 (Co-ordinates)	EV=EVbasis*10 logical	EV=EVbasis*10 logical
Rural instead of Urban	No perceptible changes	No perceptible changes except for Chlorine where they remain very slight (1.05)
Global traffic*10 (but DG traffic unchanged)	EV=EVbasis*10 only for very long range scenario (6: chlorine). See explanation 1	No change: logical it may change only victims among road users
HGV ratio* 0.1 (but DG traffic unchanged)	EV is slightly increased: logical since there is only 1.1 people per HGV and more in the other sorts of vehicles.	No change: logical it may change only victims among road users
Bus/Coach ratio* 0.1 (but DG traffic unchanged)	EV is significantly decreased: (factor 2/3) logical since there is 25 people per bus and much less in the other sorts of vehicles.	No change: logical it may change only victims among road users
HGV&Bus/Coach ratios* 0.1 (but DG traffic unchanged)	EV is significantly decreased: but less than in previous case logical	No change: logical it may change only victims among road users
Car speed* 0.1	EV is increased by a factor 1.2. Logical, when traffic is fluid, number of car passengers is 10 times denser (no change in a traffic jam).	No change: logical it may change only victims among road users
HGV/Bus/Coach speed* 0.1	EV is increased by a factor 1.3. Logical, when traffic is fluid, number of bus passengers is 10 times denser (no change in a traffic jam).	No change: logical it may change only victims among road users
Car/HGV&Bus/Coach speed* 0.1	EV is increased by a factor 1.4. Logical, conjunction of both preceding phenomena	No change: logical it may change only victims among road users
Delay for stopping approach *0.1	EV is drastically decreased by a factor 3: less road users present in the dangerous zone.	No change: logical it may change only victims among road users
Number of lanes * 0.5	EV is drastically decreased by a factor close to 2: less road users present in the dangerous zone because the same traffic jam is twice longer.	No change: logical it may change only victims among road users
Mean frequency for a HGV * 0.1	EV=EVbasis*0.1 logical because 10 times fewer accident	EV=EVbasis*0.1 logical because 10 times fewer accident
DG/HGV correction factor *2	EV=EVbasis*2 logical because 2 times more accident	EV=EVbasis*2 logical because 2 times more accident
Length*3.54 (User defined)	EV=EVbasis*3.54 logical	EV=EVbasis*3.54 logical
Population density *10	N. A.	EV=EVbasis*10 for certain scenarios and by a greater factor in other case. See explanation 2

Table A : Analysis of the output variations due to modifications of the input parameters.

Section #	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7		Scenario 8		Scenario 9		Scenario 10		All Scenarios			
	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B		
	1	0	0	0	0	0	0	0	0	2.12E-06	2.12E-06	1.37E-08	1.37E-08	0	0	1.03E-07	1.03E-07	0	0	0	0	2.23E-06		2.23E-06
2	0	0	0	0	0	0	0	0	10.000	10.000	10.000	10.000	0	0	10.000	10.000	0	0	0	0	10.000	10.000	length*10 (Coordinates)	2
3	0	0	0	0	0	0	0	0	1.000	1.000	1.050	1.050	0	0	1.000	1.000	0	0	0	0	1.000	1.000	Rural instead of Urban	3
4	0	0	0	0	0	0	0	0	1.000	1.000	1.000	1.000	0	0	1.000	1.000	0	0	0	0	1.000	1.000	Global traffic*10	4
5	0	0	0	0	0	0	0	0	1.000	1.000	1.000	1.000	0	0	1.000	1.000	0	0	0	0	1.000	1.000	HGV ratio* 0.1	5
6	0	0	0	0	0	0	0	0	1.000	1.000	1.000	1.000	0	0	1.000	1.000	0	0	0	0	1.000	1.000	Bus/Coach ratio* 0.1	6
7	0	0	0	0	0	0	0	0	1.000	1.000	1.000	1.000	0	0	1.000	1.000	0	0	0	0	1.000	1.000	HGV&Bus/Coach ratios* 0.1	7
8	0	0	0	0	0	0	0	0	1.000	1.000	1.000	1.000	0	0	1.000	1.000	0	0	0	0	1.000	1.000	Car speed* 0.1	8
9	0	0	0	0	0	0	0	0	1.000	1.000	1.000	1.000	0	0	1.000	1.000	0	0	0	0	1.000	1.000	HGV/Bus/Coach speed* 0.1	9
10	0	0	0	0	0	0	0	0	1.000	1.000	1.000	1.000	0	0	1.000	1.000	0	0	0	0	1.000	1.000	car/HGV&Bus/Coach speed* 0.1	10
11	0	0	0	0	0	0	0	0	1.000	1.000	1.000	1.000	0	0	1.000	1.000	0	0	0	0	1.000	1.000	Delay for stopping approach *0.1	11
12	0	0	0	0	0	0	0	0	1.000	1.000	1.000	1.000	0	0	1.000	1.000	0	0	0	0	1.000	1.000	Number of lanes * 0.5	12
13	0	0	0	0	0	0	0	0	0.100	0.100	0.100	0.100	0	0	0.100	0.100	0	0	0	0	0.100	0.100	Mean frequency for a HGV * 0.1	13
14	0	0	0	0	0	0	0	0	2.000	2.000	2.000	2.000	0	0	2.000	2.000	0	0	0	0	2.000	2.000	DG/HGV correction factor *2	14
15	0	0	0	0	0	0	0	0	3.536	3.536	3.536	3.536	0	0	3.536	3.536	0	0	0	0	3.536	3.536	length*3.54 (User defined)	15
16	0	0	0	0	0	0	0	0	10.669	10.669	10.000	10.000	0	0	10.000	10.000	0	0	5.01E+94	5.01E+94	33.073	33.073	Population density *10	16

Table 3 : Local population only. Influence of variations of input parameter on Expected Values. Expected Values are indicated for basic calculation (User defined section 1). Below are indicated for each section the ratio of the new Expected Values against the Basic one.

Section #	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7		Scenario 8		Scenario 9		Scenario 10		All Scenarios					
	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B				
	1	0	0	0	0	4.50E-07	4.50E-07	0	0	1.73E-05	1.73E-05	1.66E-08	1.66E-08	5.45E-06	5.45E-06	6.44E-07	6.44E-07	0.00E+00	0.00E+00	1.29E-06	1.29E-06	2.51E-05		2.51E-05	EV in BASIS calculation (fatalities/yea	1
2	0	0	0	0	10.000	10.000	0	0	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	0.000	0.000	10.000	10.000	10.000	10.000	10.000	10.000	length*10 (Coordinates)	2
3	0	0	0	0	1.000	1.000	0	0	1.000	1.000	1.051	1.051	1.000	1.000	1.000	1.000	0.000	0.000	1.068	1.068	1.003	1.003	Rural instead of Urban	3		
4	0	0	0	0	1.000	1.000	0	0	1.202	1.202	1.126	1.126	1.047	1.047	1.222	1.222	5.47E+92	5.47E+92	6.111	6.111	1.439	1.439	Global traffic*10	4		
5	0	0	0	0	1.259	1.259	0	0	1.097	1.097	1.000	1.000	1.148	1.148	1.091	1.091	0.000	0.000	1.000	1.000	1.106	1.106	HGV ratio* 0.1	5		
6	0	0	0	0	0.724	0.724	0	0	0.724	0.724	0.997	0.997	0.759	0.759	0.738	0.738	0.000	0.000	0.420	0.420	0.717	0.717	Bus/Coach ratio* 0.1	6		
7	0	0	0	0	0.912	0.912	0	0	0.796	0.796	0.997	0.997	0.871	0.871	0.801	0.801	0.000	0.000	0.646	0.646	0.807	0.807	HGV&Bus/Coach ratios* 0.1	7		
8	0	0	0	0	1.000	1.000	0	0	1.009	1.009	1.053	1.053	1.000	1.000	1.019	1.019	2.74E+92	2.74E+92	3.198	3.198	1.130	1.130	Car speed* 0.1	8		
9	0	0	0	0	1.000	1.000	0	0	1.018	1.018	1.067	1.067	1.000	1.000	1.019	1.019	3.45E+92	3.45E+92	3.978	3.978	1.179	1.179	HGV/Bus/Coach speed* 0.1	9		
10	0	0	0	0	1.000	1.000	0	0	1.028	1.028	1.126	1.126	1.000	1.000	1.043	1.043	5.47E+92	5.47E+92	6.111	6.111	1.304	1.304	car/HGV&Bus/Coach speed* 0.1	10		
11	0	0	0	0	1.000	1.000	0	0	0.432	0.432	1.000	1.000	0.316	0.316	0.390	0.390	0.000	0.000	1.000	1.000	0.446	0.446	Delay for stopping approach *0.1	11		
12	0	0	0	0	0.525	0.525	0	0	0.688	0.688	1.000	1.000	0.631	0.631	0.717	0.717	0.000	0.000	1.000	1.000	0.690	0.690	Number of lanes * 0.5	12		
13	0	0	0	0	0.100	0.100	0	0	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.000	0.000	0.100	0.100	0.100	0.100	Mean frequency for a HGV * 0.1	13		
14	0	0	0	0	2.000	2.000	0	0	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	0.000	0.000	2.000	2.000	2.000	2.000	DG/HGV correction factor *2	14		
15	0	0	0	0	3.536	3.536	0	0	3.536	3.536	3.536	3.536	3.536	3.536	3.536	3.536	0.000	0.000	3.536	3.536	3.536	3.536	length*3.54 (User defined)	15		
16	0	0	0	0	1.259	1.259	0	0	2.669	2.669	9.882	9.882	2.884	2.884	2.848	2.848	0.000	0.000	43.778	43.778	4.808	4.808	Population density *10	16		

Table 4 : Road Users and Local population simultaneously. Influence of variations of input parameter on Expected Values. Expected Values are indicated for basic calculation (User defined section 1). Below are indicated for each section the ratio of the new Expected Values against the Basic one.

Section #	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7		Scenario 8		Scenario 9		Scenario 10		All Scenarios			
	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B		
1	0	0	0	0	0	0	0	0	9.66E-07	9.66E-07	2.74E-09	2.74E-09	1.12E-06	1.12E-06	2.67E-08	2.67E-08	0	0	1.29E-06	1.29E-06	3.40E-06	3.40E-06	EV in BASIS calculation (fatalities/yea	1

Table 5 : Road Users and Local population simultaneously. Difference between basic calculation of table 4 and sum of basic calculations of tables 2 and 3. Difference is positive because of reasons given by explanation 2 of paragraph 3.

All Scenarios									
Direction A				Direction B					
30	80	200	500	30	80	200	500		
4.1837E-05	2.2453E-05	2.1853E-06	4.2017E-09	4.1837E-05	2.2453E-05	2.1853E-06	4.2017E-09	Individual Risk in BASIS calculation (1/year)	1
1	1	1	1	1	1	1	1	length*10 (Coordinates)	2
1.07	1.11	1.17	1.05	1.07	1.11	1.17	1.05	Rural instead of Urban	3
1	1	1	1	1	1	1	1	Global traffic*10	4
1	1	1	1	1	1	1	1	HGV ratio* 0.1	5
1	1	1	1	1	1	1	1	Bus/Coach ratio* 0.1	6
1	1	1	1	1	1	1	1	HGV&Bus/Coach ratios* 0.1	7
1	1	1	1	1	1	1	1	Car speed* 0.1	8
1	1	1	1	1	1	1	1	HGV/Bus/Coach speed* 0.1	9
1	1	1	1	1	1	1	1	car/HGV&Bus/Coach speed* 0.1	10
1	1	1	1	1	1	1	1	Delay for stopping approach *0.1	11
1	1	1	1	1	1	1	1	Number of lanes * 0.5	12
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	Mean frequency for a HGV * 0.1	13
2	2	2	2	2	2	2	2	DG/HGV correction factor *2	14
1	1	1	1	1	1	1	1	length*3.54 (User defined)	15
1	1	1	1	1	1	1	1	Population density *10	16

Table 6 : Influence of variations of input parameter on Individual Risk levels at 4 different distances from the route (30, 80, 200 and 500 m). Individual Risk levels are indicated for basic calculation (User defined section 1). Below are indicated for each section the ratio of the new Individual Risk against the Basic one.

Section #	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7		Scenario 8		Scenario 9		Scenario 10		All Scenarios			
	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B		
1	0	0	0	0	0	0	0	0	4.32E-07	4.32E-07	2.23E-10	2.23E-10	1.57E-07	1.57E-07	2.37E-08	2.37E-08	0	0	0	0	6.13E-07	6.13E-07	EV in BASIS calculation (fatalities/yea	1
2	0	0	0	0	0	0	0	0	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	0	0	0	0	10.000	10.000	length*10 (Coordinates)	2
3	0	0	0	0	0	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0	0	0	0	1.000	1.000	Rural instead of Urban	3
4	0	0	0	0	1.56E+92	1.56E+92	0	0	14.610	14.610	10.000	10.000	10.000	10.000	10.000	10.000	5.47E+92	5.47E+92	7.37E+93	7.37E+93	26.411	26.411	Global traffic*10	4
5	0	0	0	0	0	0	0	0	1.035	1.035	1.010	1.010	1.000	1.000	1.000	1.000	0	0	0	0	1.025	1.025	HGV ratio* 0.1	5
6	0	0	0	0	0	0	0	0	0.250	0.250	0.574	0.574	0.575	0.575	0.060	0.060	0	0	0	0	0.326	0.326	Bus/Coach ratio* 0.1	6
7	0	0	0	0	0	0	0	0	0.262	0.262	0.581	0.581	0.575	0.575	0.060	0.060	0	0	0	0	0.334	0.334	HGV&Bus/Coach ratios* 0.1	7
8	0	0	0	0	7.82E+91	7.82E+91	0	0	7.184	7.184	4.837	4.837	5.012	5.012	4.786	4.786	2.74E+92	2.74E+92	3.60E+93	3.60E+93	12.973	12.973	Car speed* 0.1	8
9	0	0	0	0	9.85E+91	9.85E+91	0	0	9.044	9.044	6.089	6.089	6.310	6.310	6.026	6.026	3.45E+92	3.45E+92	4.53E+93	4.53E+93	16.332	16.332	HGV/Bus/Coach speed* 0.1	9
10	0	0	0	0	1.56E+92	1.56E+92	0	0	14.610	14.610	10.000	10.000	10.000	10.000	10.000	10.000	5.47E+92	5.47E+92	7.37E+93	7.37E+93	26.411	26.411	car/HGV&Bus/Coach speed* 0.1	10
11	0	0	0	0	0	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0	0	0	0	1.000	1.000	Delay for stopping approach *0.1	11
12	0	0	0	0	0	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0	0	0	0	1.000	1.000	Number of lanes * 0.5	12
13	0	0	0	0	0	0	0	0	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0	0	0	0	0.100	0.100	Mean frequency for a HGV * 0.1	13
14	0	0	0	0	0	0	0	0	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	0	0	0	0	2.000	2.000	DG/HGV correction factor *2	14
15	0	0	0	0	0	0	0	0	3.536	3.536	3.536	3.536	3.536	3.536	3.536	3.536	0	0	0	0	3.536	3.536	length*3.54 (User defined)	15

Table 7 : Road Users only. Influence of variations of input parameter on Expected Values Same calculation as in table 2 except that delays between accident and scenario are all equal to zero. Expected Values are indicated for basic calculation (User defined section 1). Below are indicated for each section the ratio of the new Expected Values against the Basic one.

Section #	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7		Scenario 8		Scenario 9		Scenario 10		All Scenarios			
	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B		
1	0	0	0	0	0	0	0	0	0.030	0.030	1	1	0.036	0.036	0.046	0.046	0	0	0	0	1.113	1.113	EV in BASIS calculation (fatalities/yea	1
2	0	0	0	0	0	0	0	0	0.030	0.030	1	1	0.036	0.036	0.046	0.046	0	0	0	0	1.113	1.113	length*10 (Coordinates)	2
3	0	0	0	0	0	0	0	0	0.030	0.030	1	1	0.036	0.036	0.046	0.046	0	0	0	0	1.113	1.113	Rural instead of Urban	3
4	0	0	0	0	0	0	0	0	0.353	0.353	1	1	0.347	0.347	0.361	0.361	0	0	0	0	18.219	18.219	Global traffic*10	4
5	0	0	0	0	0	0	0	0	0.028	0.028	1	1	0.032	0.032	0.042	0.042	0	0	0	0	1.014	1.014	HGV ratio* 0.1	5
6	0	0	0	0	0	0	0	0	0.011	0.011	1	1	0.032	0.032	0.004	0.004	0	0	0	0	0.543	0.543	Bus/Coach ratio* 0.1	6
7	0	0	0	0	0	0	0	0	0.010	0.010	1	1	0.025	0.025	0.004	0.004	0	0	0	0	0.470	0.470	HGV&Bus/Coach ratios* 0.1	7
8	0	0	0	0	0	0	0	0	0.215	0.215	1	1	0.182	0.182	0.216	0.216	0	0	0	0	11.892	11.892	Car speed* 0.1	8
9	0	0	0	0	0	0	0	0	0.270	0.270	1	1	0.229	0.229	0.270	0.270	0	0	0	0	14.362	14.362	HGV/Bus/Coach speed* 0.1	9
10	0	0	0	0	0	0	0	0	0.432	0.432	1	1	0.363	0.363	0.436	0.436	0	0	0	0	20.552	20.552	car/HGV&Bus/Coach speed* 0.1	10
11	0	0	0	0	0	0	0	0	0.099	0.099	1	1	0.275	0.275	0.198	0.198	0	0	0	0	3.949	3.949	Delay for stopping approach *0.1	11
12	0	0	0	0	0	0	0	0	0.049	0.049	1	1	0.072	0.072	0.072	0.072	0	0	0	0	1.876	1.876	Number of lanes * 0.5	12
13	0	0	0	0	0	0	0	0	0.030	0.030	1	1	0.036	0.036	0.046	0.046	0	0	0	0	1.113	1.113	Mean frequency for a HGV * 0.1	13
14	0	0	0	0	0	0	0	0	0.030	0.030	1	1	0.036	0.036	0.046	0.046	0	0	0	0	1.113	1.113	DG/HGV correction factor *2	14
15	0	0	0	0	0	0	0	0	0.030	0.030	1	1	0.036	0.036	0.046	0.046	0	0	0	0	1.113	1.113	length*3.54 (User defined)	15

Table 8 : Road Users only. Influence of variations of input parameter on Expected Values Values Comparison between outputs of table 7 (numerator) and table 2 (denominator) expressed as ratios.

Section #	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7		Scenario 8		Scenario 9		Scenario 10		All Scenarios			
	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B		
	1	0	0	0	0	4.50E-07	4.50E-07	0	0	1.48E-05	1.48E-05	1.00E-08	1.00E-08	5.45E-06	5.45E-06	6.41E-07	6.41E-07	0	0	1.12E-06	1.12E-06	2.25E-05		2.25E-05
2	0	0	0	0	10.000	10.000	0	0	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	0	0	10.000	10.000	10.000	10.000	length*10 (Coordinates)	2
3	0	0	0	0	1.000	1.000	0	0	1.000	1.000	1.053	1.053	1.000	1.000	1.000	1.000	0	0	1.063	1.063	1.003	1.003	Rural instead of Urban	3
4	0	0	0	0	1.000	1.000	0	0	1.125	1.125	1.136	1.136	1.047	1.047	1.268	1.268	5.47E+92	5.47E+92	6.300	6.300	1.389	1.389	Global traffic*10	4
5	0	0	0	0	1.259	1.259	0	0	1.140	1.140	1.000	1.000	1.148	1.148	1.069	1.069	0	0	1.000	1.000	1.135	1.135	HGV ratio* 0.1	5
6	0	0	0	0	0.724	0.724	0	0	0.717	0.717	0.996	0.996	0.759	0.759	0.742	0.742	0	0	0.553	0.553	0.720	0.720	Bus/Coach ratio* 0.1	6
7	0	0	0	0	0.912	0.912	0	0	0.825	0.825	0.996	0.996	0.871	0.871	0.789	0.789	0	0	0.683	0.683	0.830	0.830	HGV&Bus/Coach ratios* 0.1	7
8	0	0	0	0	1.000	1.000	0	0	1.005	1.005	1.058	1.058	1.000	1.000	1.022	1.022	2.74E+92	2.74E+92	3.253	3.253	1.128	1.128	Car speed* 0.1	8
9	0	0	0	0	1.000	1.000	0	0	1.011	1.011	1.074	1.074	1.000	1.000	1.022	1.022	3.45E+92	3.45E+92	4.067	4.067	1.175	1.175	HGV/Bus/Coach speed* 0.1	9
10	0	0	0	0	1.000	1.000	0	0	1.016	1.016	1.136	1.136	1.000	1.000	1.049	1.049	5.47E+92	5.47E+92	6.300	6.300	1.300	1.300	car/HGV&Bus/Coach speed* 0.1	10
11	0	0	0	0	1.000	1.000	0	0	0.474	0.474	1.000	1.000	0.316	0.316	0.404	0.404	0	0	1.000	1.000	0.471	0.471	Delay for stopping approach *0.1	11
12	0	0	0	0	0.525	0.525	0	0	0.624	0.624	1.000	1.000	0.631	0.631	0.752	0.752	0	0	1.000	1.000	0.646	0.646	Number of lanes * 0.5	12
13	0	0	0	0	0.100	0.100	0	0	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0	0	0.100	0.100	0.100	0.100	Mean frequency for a HGV * 0.1	13
14	0	0	0	0	2.000	2.000	0	0	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	0	0	2.000	2.000	2.000	2.000	DG/HGV correction factor *2	14
15	0	0	0	0	3.536	3.536	0	0	3.536	3.536	3.536	3.536	3.536	3.536	3.536	3.536	0	0	3.536	3.536	3.536	3.536	length*3.54 (User defined)	15
16	0	0	0	0	1.259	1.259	0	0	2.274	2.274	9.870	9.870	2.884	2.884	3.053	3.053	0	0	50.149	50.149	4.803	4.803	Population density *10	16

Table 9 : Road Users and local population simultaneously. Influence of variations of input parameter on Expected Values Same calculation as in table 4 except that « Reference » meteorological conditions are replaced by « Sea » meteorological conditions. Expected Values are indicated for basic calculation (User defined section 1). Below are indicated for each section the ratio of the new Expected Values against the Basic one.

Section #	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7		Scenario 8		Scenario 9		Scenario 10		All Scenarios			
	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B	Direction A	Direction B		
	1	0	0	0	0	1	1	0	0	0.860	0.860	0.602	0.602	1	1	0.996	0.996	0	0	0.868	0.868	5.325E+00		5.3249238
2	0	0	0	0	1	1	0	0	0.860	0.860	0.602	0.602	1	1	0.996	0.996	0	0	0.868	0.868	5.3249238	5.3249238	length*10 (Coordinates)	2
3	0	0	0	0	1	1	0	0	0.860	0.860	0.603	0.603	1	1	0.996	0.996	0	0	0.864	0.864	5.323	5.323	Rural instead of Urban	3
4	0	0	0	0	1	1	0	0	0.804	0.804	0.608	0.608	1	1	1.034	1.034	0	0	0.894	0.894	5.139	5.139	Global traffic*10	4
5	0	0	0	0	1	1	0	0	0.894	0.894	0.602	0.602	1	1	0.975	0.975	0	0	0.868	0.868	5.468	5.468	HGV ratio* 0.1	5
6	0	0	0	0	1	1	0	0	0.852	0.852	0.601	0.601	1	1	1.001	1.001	0	0	1.142	1.142	5.352	5.352	Bus/Coach ratio* 0.1	6
7	0	0	0	0	1	1	0	0	0.891	0.891	0.601	0.601	1	1	0.981	0.981	0	0	0.918	0.918	5.478	5.478	HGV&Bus/Coach ratios* 0.1	7
8	0	0	0	0	1	1	0	0	0.857	0.857	0.605	0.605	1	1	0.998	0.998	0	0	0.882	0.882	5.314	5.314	Car speed* 0.1	8
9	0	0	0	0	1	1	0	0	0.853	0.853	0.606	0.606	1	1	0.998	0.998	0	0	0.887	0.887	5.306	5.306	HGV/Bus/Coach speed* 0.1	9
10	0	0	0	0	1	1	0	0	0.850	0.850	0.608	0.608	1	1	1.002	1.002	0	0	0.894	0.894	5.306	5.306	car/HGV&Bus/Coach speed* 0.1	10
11	0	0	0	0	1	1	0	0	0.944	0.944	0.602	0.602	1	1	1.033	1.033	0	0	0.888	0.888	5.629	5.629	Delay for stopping approach *0.1	11
12	0	0	0	0	1	1	0	0	0.779	0.779	0.602	0.602	1	1	1.044	1.044	0	0	0.888	0.888	4.987	4.987	Number of lanes * 0.5	12
13	0	0	0	0	1	1	0	0	0.860	0.860	0.602	0.602	1	1	0.996	0.996	0	0	0.868	0.868	5.3249238	5.3249238	Mean frequency for a HGV * 0.1	13
14	0	0	0	0	1	1	0	0	0.860	0.860	0.602	0.602	1	1	0.996	0.996	0	0	0.868	0.868	5.3249238	5.3249238	DG/HGV correction factor *2	14
15	0	0	0	0	1	1	0	0	0.860	0.860	0.602	0.602	1	1	0.996	0.996	0	0	0.868	0.868	5.3249238	5.3249238	length*3.54 (User defined)	15
16	0	0	0	0	1	1	0	0	0.732	0.732	0.601	0.601	1	1	1.067	1.067	0	0	0.994	0.994	5.320	5.320	Population density *10	16

Table 10 : Road Users and local population simultaneously. Influence of variations of input parameter on Expected Values Comparison between outputs of table 9 (numerator) and table 4 (denominator) expressed as ratios.

Scenario #	Open	
1	0	HGV fire 20 MW
2	0	HGV fire 100 MW
3	300	BLEVE of a 50kg LPG cylinder
4	0	Motor spirit pool fire
5	150	VCE of motor spirit
6	0	Chlorine release from a 20 tons tank
7	300	BLEVE of an 18 tons LPG tank
8	150	VCE from an 18 tons LPG tank
9	0	Torch fire from an 18 tons LPG tank
10	0	Ammonia release from an 18 tons tank

Table 11 List of delays between the accident and the different scenarios used for computations shown in tables 2 to 5

Scenario #	Related probability
1	0,0416
2	0,0085
3	0,0006
4	0,0067
5	0,0007
6	0,0444
7	0,0005
8	0,0005
9	0,0046
10	0,0755

Table 12 List of scenario rates used in computations

Stability	A	F	A	D	F	C	D
Wind speed (m/s)	1,5	1,5	3	3	3	6	10
	Meteo #						
	1	2	3	4	5	6	7
Reference	0,2	0,2	0,16	0,08	0,16	0,1	0,1
Mountainous	0,2	0,2	0,08	0,04	0,08	0,3	0,1
Sea	0,1	0,1	0,12	0,06	0,12	0,2	0,3
Inland	0,2	0,2	0,16	0,08	0,16	0,1	0,1

Table 13 List of meteorological distribution available in computations (changed by expert user)

Air exchange rate (1/heure)	Urban			Rural				
	NORMAL	QUIET	PEAK	NORMAL	QUIET	PEAK		
2,5	0,3	0,4	0,15	0,3	0,25	0,2	Road users	Road vehicles with closed windows and ventilation out
25	0,3	0,4	0,3	0,3	0,5	0,3		Road vehicles with closed windows but ventilation on
1000	0,2	0,1	0,3	0,15	0,1	0,2		Road vehicles with windows open
1,00E+30	0,2	0,1	0,25	0,25	0,15	0,3	Local population	Pedestrians escaping
0,8	0,3	0,7	0,2	0,4	0,8	0,3		Private house
7	0,4	0,2	0,4	0,25	0,1	0,2		Building and premi-ses open to the public
1,00E+30	0,3	0,1	0,4	0,35	0,1	0,5		Pedestrians

Table 14 Distributions used for road user and local population exposure to toxic atmospheres.

ANNEX 2

Parameterised Sensitivity Study for Tunnel Pre-Conditioner

1. Scope

The objective of this sensitivity study is to demonstrate how modification of input parameters can affect the output results obtained with the Tunnel Pre-Conditioner. These output results include:

- hazard ranges to specified fatality and injury levels;
- tunnel lengths corresponding to specified damage levels.

2. Approach Used

The following approach has been adopted:

- define a simple 'base' case and perform a calculation using the Pre-Conditioner;
- repeat the calculations varying only one parameter at a time;
- compare the results with the base case.

For the present purposes, a qualitative approach has been adopted for comparing the sensitivity cases. The emphasis has been placed on the overall characteristics of the results rather than the fine details. A key reason for this relates to the calculation methods employed in the Pre-Conditioner. The tunnel is divided into a small number of segments for the purpose of defining the gradients and ventilation regimes. For calculation purposes, these segments are sub-divided into 'sub-segments'. The calculations of temperature, concentration and other physical parameters are carried out at the end-points of each sub-segment. Determination of fatality and damage extents involves interpolation between these calculation points. Small changes of parameter values at calculation points can therefore lead to large relative changes locally. Quantitative comparisons can therefore be rather misleading when trying to understand the overall behaviour of the Pre-Conditioner.

The base case definition is given in Table 1.

Table 1 - Definition of base case

cross-sectional area = 50 m ² , length = 1000 m, level ventilation velocity = 1 m/s no drainage bi-directional traffic, light traffic density no emergency exits inside tunnel no emergency communications systems cut and cover construction roof thickness = 0.5 m internal road support structure - thickness = 0.2 m no fire protection lining 50m sub-segment length
--

The table below lists the cases which have been considered.

Table 2 - Sensitivity cases

case	description
1	base case
2	25m sub-segment length
3	ventilation velocity = 2m/s (sub-segment length = 50m)
4	drainage area = 0.075m ² at 20m intervals
5	distance between emergency exits = 250m
6	traffic density = peak, moving B to A
7	emergency management systems eg. PA + CCTV
8	measures from cases 3, 4, 5, 7, plus fire protection lining
9	same as case 8, except sub-segment length = 25m

Two cases have been considered using smaller sub-segment lengths in order to gain some understanding of how sensitive the Pre-Conditioner results are to this input parameter. Regarding the other cases, it is fairly clear that parameters such as ventilation velocity, drainage and evacuation-related aspects could have a significant influence on fatality and damage results. Traffic density and direction parameters (case 6) are considered in the calculation of over-pressures in the event of a vapour cloud explosion (VCE).

3. Results

3.1 Fatalities

Figures 1 to 8 illustrate the variation of results between the sensitivity cases listed in Table 2, for the different accident scenarios. Note that the results of the LPG 18te tank BLEVE and VCE are identical and have therefore been illustrated together in Figure 7.

For each accident scenario, the figures illustrate the predicted extents of the regions corresponding to 90, 50 and 10% fatalities along the tunnel. For each sensitivity case, the top bar represents 90% fatalities, the middle bar represents 50% fatalities and the lower bar represents 0% fatalities. A key for all figures is overlaid on Figure 7.

The results are now discussed for each scenario in turn.

Scenario 1: HGV fire, 20MW

The cases are considered in turn.

Firstly, comparing cases 1 (base case) and 2, it can be seen that sub-segment length has some effect on the upstream extent of fatalities, but the difference is relatively small.

Case 3 is very different because the increased ventilation velocity is greater than the critical velocity for this accident scenario, and consequently, all the smoke is blown downstream (to the right). The increased velocity also leads to increased dilution and the extent of fatalities is generally reduced. The fatalities on the upstream side are due to thermal radiation effects rather than smoke toxicity.

The results for cases 4 and 6 are identical to case 1, since drainage and traffic distribution and density are not used in the fire scenario calculations.

In case 5, which considered emergency exits at 250m spacing along the tunnel, it is evident that the downstream extent of fatalities is reduced because occupants can move to a place of safety more quickly. Likewise, in case 7, the existence of emergency detection and communications systems reduces the overall time taken for occupants to reach an exit. In this latter case, however, the reduction in time relates to the time taken to recognise that there is a fire and that evacuation should commence.

Cases 8 and 9 show the combined benefits of smoke control, more closely spaced emergency exits and emergency systems. Comparing cases 8 and 9, there is a noticeable difference between the results for the 50m and 25m sub-segment lengths. The reason for this is that, with the combined effects of the different mitigation measures, the extent of the region affected by the fire is now quite localised, ie. less than 100m. To resolve such a localised incident would require small sub-segment lengths.

Scenario 2: HGV fire, 100MW

The relative differences between the various cases generally follow the same pattern for this accident scenario, as for the 20MW HGV fire. However, case 3 indicates that the increased ventilation velocity does not exceed the critical velocity needed to prevent backlayering. As a result, there is smoke spreading and fatalities in both upstream and downstream directions. The existence of emergency exits (case 5) and emergency management systems (case 7) both lead to a substantial reduction of hazard ranges. Comparing cases 8 and 9, there are differences between the results for the 50m and 25m sub-segment lengths, but less so than for the 20MW fire because of the greater extent affected by this larger fire scenario.

Scenario 3: LPG, BLEVE, 50kg cylinder

This scenario has more localised effects. It is predicted that there are 10% fatalities over a distance of about 150m. The extent of 50% fatalities is much less. It is noticeable that the results do differ slightly for the cases with 25m sub-segment lengths, namely cases 2 and 9. This relates to the resolution used in the calculations and not due to any physical effects. With such a localised incident, the results can be rather sensitive to the positions of the calculation points relative to the accident itself. None of the cases have 90% fatalities.

Scenario 4: Motor spirit, Pool fire, 20te tank

The heat release rate for this scenario is predicted to be about 190MW, taking into account the airflow available for combustion. The results for the pool fire indicate a greater extent of fatalities than for the 20MW and 100MW fires.

The results of the pool fire scenario, show in Figure 4, exhibit some similar characteristics to those of the 20MW and 100MW fires, in terms of the relative differences between the sensitivity cases. The existence of emergency exits (case 5) and emergency management systems (case 7) again leads to reduced hazard ranges.

Scenario 5: Motor spirit, VCE, 20te tank

The results for this case are shown in Figure 5. Comparing cases 1 (base case) and 2, it can be seen that the differences between the results obtained with 50m and 25m sub-segment lengths are insignificant. Case 3, with the increased ventilation velocity, has slightly increased hazard ranges, due to the corresponding increase in evaporation from the pool.

The hazard ranges for case 4 are greatly reduced compared to the base case, because the tunnel drainage leads to a smaller pool area and reduced evaporation.

For cases 5 and 7, which both address evacuation aspects, fatalities are reduced downstream of the incident. The effect is only really noticeable in this case for the 10% fatality band, because the 90% and 50% bands extend only about 150m beyond the incident anyway.

For cases 8 and 9, the combined benefits of drainage and emergency management systems leads to relatively small hazard ranges. It is predicted for these cases, that fatalities do not reach 90% anywhere.

Scenario 6: Chlorine, Toxic release, 20te tank

From Figure 6, it is shown that the chlorine scenario is more severe than the fire scenarios in terms of fatalities. In the base case, fatalities exceed 90% everywhere in the tunnel. With increased tunnel ventilation velocity (case 3), the gas is blown downstream and there are very few fatalities upstream of the incident. Drainage (case 4) and traffic (case 6) have no impact on the calculations for toxic release. Spacing of emergency exits (case 5) has no effect in this case. The reason for this is that detection of the incident is assumed to be delayed in comparison to that for a fire; thus evacuation starts too late to reduce fatalities. Emergency management systems (case 7) do have some effect further downstream, where it is predicted that occupants receive sufficient warning to evacuate via the downstream portal.

For cases 8 and 9, the combination of increased ventilation velocity and emergency management systems clearly has an impact on the distribution of fatalities. It should be noted that in this case, the toxic gas advances downstream more rapidly than the assumed evacuation speed of occupants; hence the adverse effects of enhanced downstream spread outweigh the potential advantages of the emergency exits and management system.

Scenario 7: LPG, BLEVE, 18te tank & Scenario 8: LPG, VCE, 18te tank

Due to the nature of these scenarios, the hazard ranges would be expected to be insensitive to parameters relating to ventilation and drainage. The results are also insensitive to traffic density simply because the physical effects are severe enough in almost all circumstances to cause 100% fatalities throughout the tunnel.

Scenario 10: Ammonia, Toxic release, 18te tank

For this scenario, a tunnel ventilation velocity of 1 m/s is sufficient to prevent gas spreading upstream of the incident location. In the base case, it is assumed that there would be little advance warning of the hazard. Occupants would realise the danger only when the gas reached them. Case 3, with the increased tunnel velocity, actually results in increased fatalities because the gas moves more rapidly than the evacuees. The results are insensitive to parameters relating to drainage and traffic density.

The most significant result is obtained in case 7, which relates to emergency management systems. The downstream fatality ranges are reduced by approximately 200m because occupants near the downstream portal are given sufficient advance warning of the emergency to escape.

For cases 8 and 9, the benefits arising from an emergency management system are counteracted by the adverse effects of an increased ventilation velocity, as for accident scenario 6.

3.2 Structural damage and costs

Figures 9 to 15 show the structural damage results corresponding to the fatality results discussed above. It is immediately apparent that these particular results are generally much less sensitive to the inputs. In some cases, this is not surprising since parameters such as emergency exit spacing and the presence of emergency management systems affect evacuation rather than the physical consequences. Another key factor is the basis of the damage indicators used. Damage is assumed to occur only when certain thresholds are exceeded. For example, a concrete dividing wall is considered to fail, and thus incur damage costs, only when spalling damage exceeds half the thickness of the wall.

Comparing the three fire scenarios (Figures 9, 10 and 12), it is evident that the structural damage increases with fire size (the pool fire has a heat release rate of about 190 MW). Sensitivity cases 8 and 9 included fire protection lining and it can be seen that there is no structural damage for these cases. The absence of structural damage for the pool fire scenario relates to the duration which is shorter than the 1 hour duration assumed for the HGV fires.

The motor spirit VCE exhibits much greater sensitivity to the input parameters in Table 1. Drainage affects the severity of the VCE substantially. This is the key effect which can be observed in cases 4, 8 and 9.

To illustrate the circumstances when serious structural damage might be predicted, an extra sensitivity case (case 10) has been considered. This corresponds to the base case in general, but incorporates two particular changes. Firstly, the pool fire scenario has been modified to consider a 50mm breach diameter instead of the default 100mm breach scenario. This smaller breach still leads to a major fire, but the duration is extended to just over 1 hour. The second modification to the base case is the reduction of concrete roof slab thickness to 0.25m, reduction of internal

structure thickness to 0.1m and the removal of the water component above the tunnel, ie. reduced overburden.

The structural damage results for the set of accident scenarios are shown in Figure 16. It can be seen that, for the pool fire scenario, major structural damage is now predicted over a small length of tunnel, corresponding to spalling effects arising from prolonged exposure to the hot combustion products. The results for scenarios 7 and 8 (LPG 18te tank BLEVE and VCE respectively) show serious damage due to overpressures generated in those scenarios. It can be seen that the BLEVE is predicted to cause more severe damage but affect a shorter extent of tunnel than the VCE scenario. The tunnel structure itself is damaged in this BLEVE scenario. Reduction of the thickness of internal concrete structures has also led to an increase in the extent of damage to these elements of the tunnel.

4. Conclusions

From this simple sensitivity study, it can be seen that changes in certain parameters can lead to major changes in the predicted hazard ranges for a significant number of accident scenario and location combinations.

Factors relating to evacuation can have a profound effect on predicted levels of fatalities and injuries. The spacing between exits can have a significant effect on the results. The presence of emergency communications systems, such as PA and CCTV systems, can reduce the time taken to recognise and respond to an emergency and evacuate from the tunnel. The assumptions made in the evacuation sub-model of the Pre-Conditioner can have a major impact and their suitability for a particular country and tunnel should be considered by the user.

In addition to the above, parameters such as ventilation flow and drainage area can also have a major effect on the predicted consequences of certain accident scenarios. Due to the disparity of the accident scenarios, it is also important to recognise that the consequences of changing a parameter may appear to be inconsistent. For example, an increase in ventilation flow rate may reduce the consequences of certain scenarios (perhaps due to increased dilution of toxic gases), but could also lead to more adverse conditions for other scenarios (such as increased motor spirit evaporation rate prior to a VCE).

Regarding sub-segment length, for certain scenarios the distances over which significant effects are experienced may be limited in one or both directions. For example, upwind of a fire, the temperatures may decay very rapidly when the ventilation flow is strong. The base case employed a sub-segment length of 50m. To resolve localised effects, smaller sub-segment lengths may sometimes be beneficial.

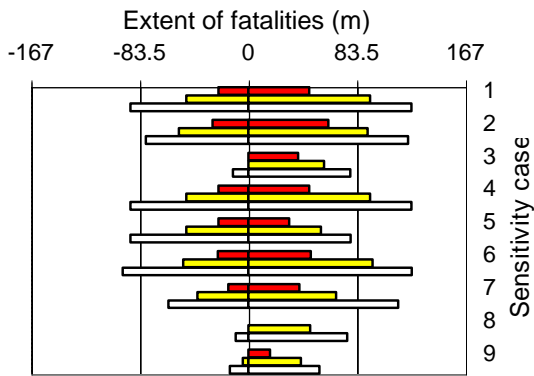


Figure 1 - HGV fire, 20MW

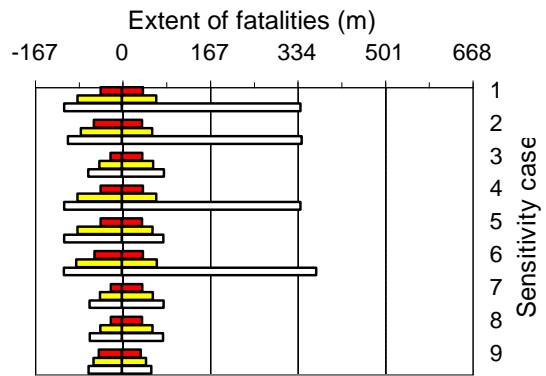


Figure 2 - HGV fire, 100MW

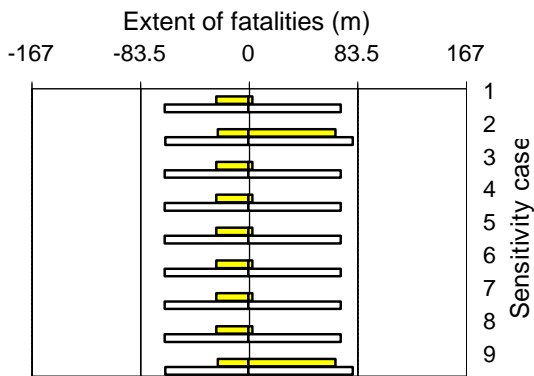


Figure 3 - LPG BLEVE, 50kg cylinder

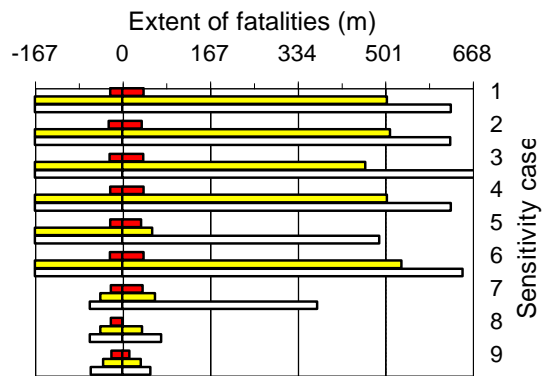


Figure 4 - Motor spirit pool fire, 20te tank

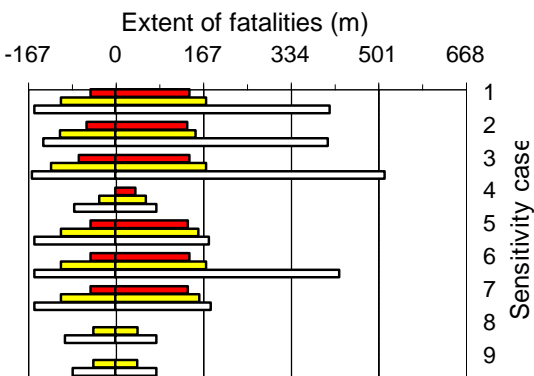


Figure 5 - Motor spirit VCE, 20te tank

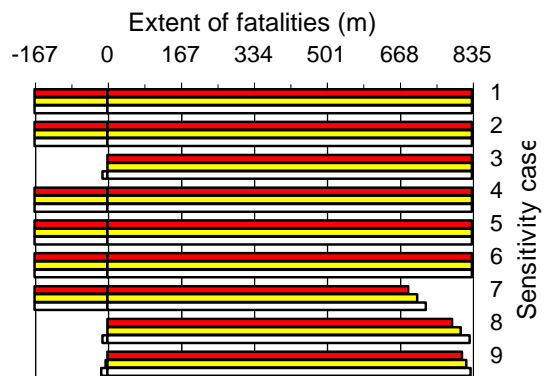


Figure 6 - Chlorine release, 20te tank

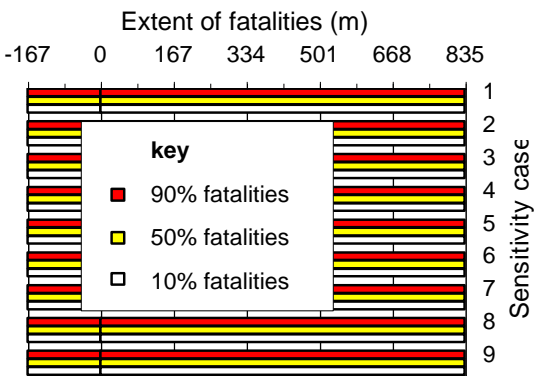


Figure 7 - LPG BLEVE/VCE, 18te tank

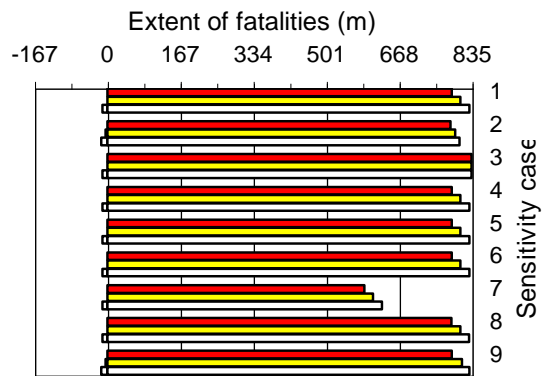


Figure 8 - Ammonia release, 18te tank

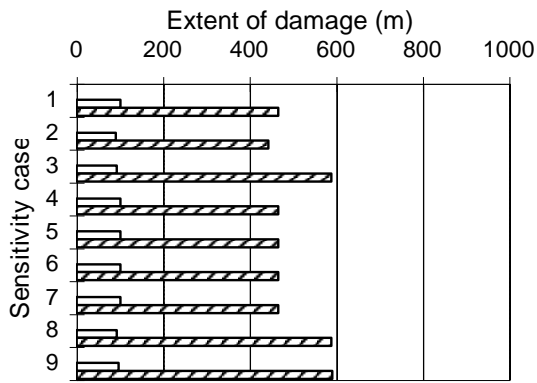


Figure 9 - HGV fire, 20MW

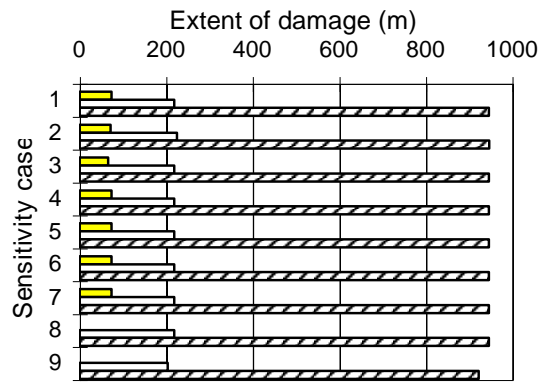


Figure 10 - HGV fire, 100MW

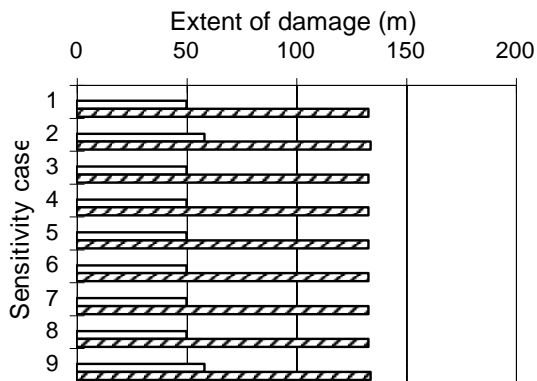


Figure 11 - LPG BLEVE, 50kg cylinder

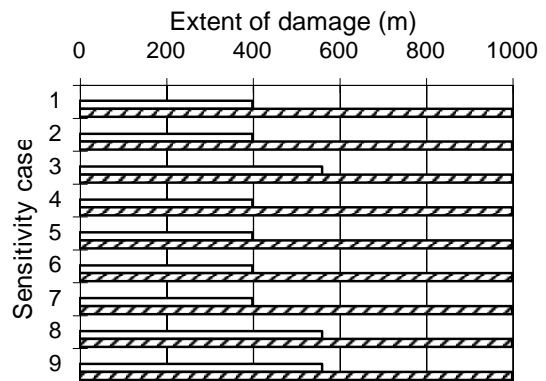


Figure 12 - Motor spirit pool fire, 20te tank

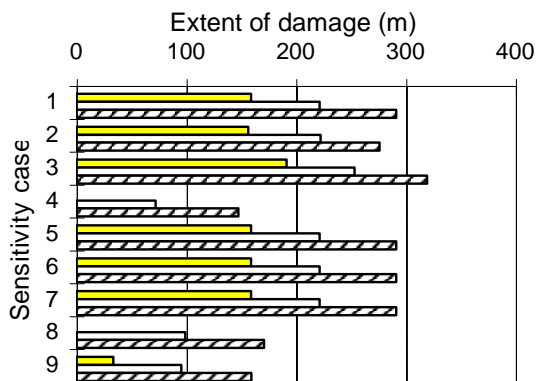


Figure 13 - Motor spirit VCE, 20te tank

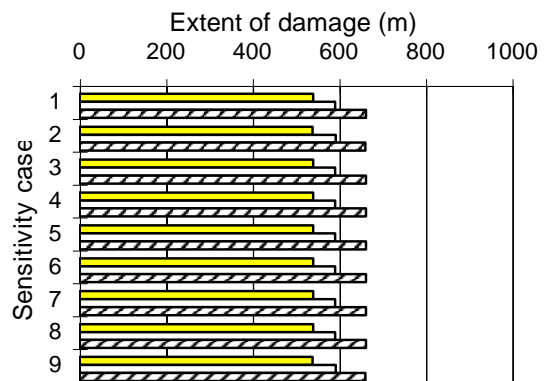


Figure 14 - LPG BLEVE, 18te tank

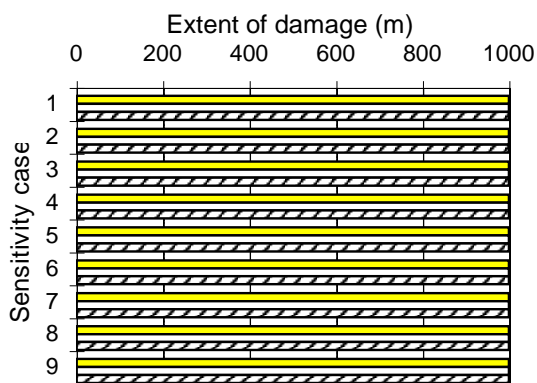
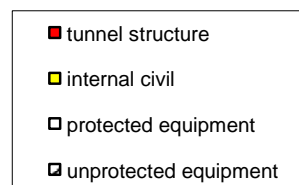


Figure 15 - LPG VCE, 18te tank



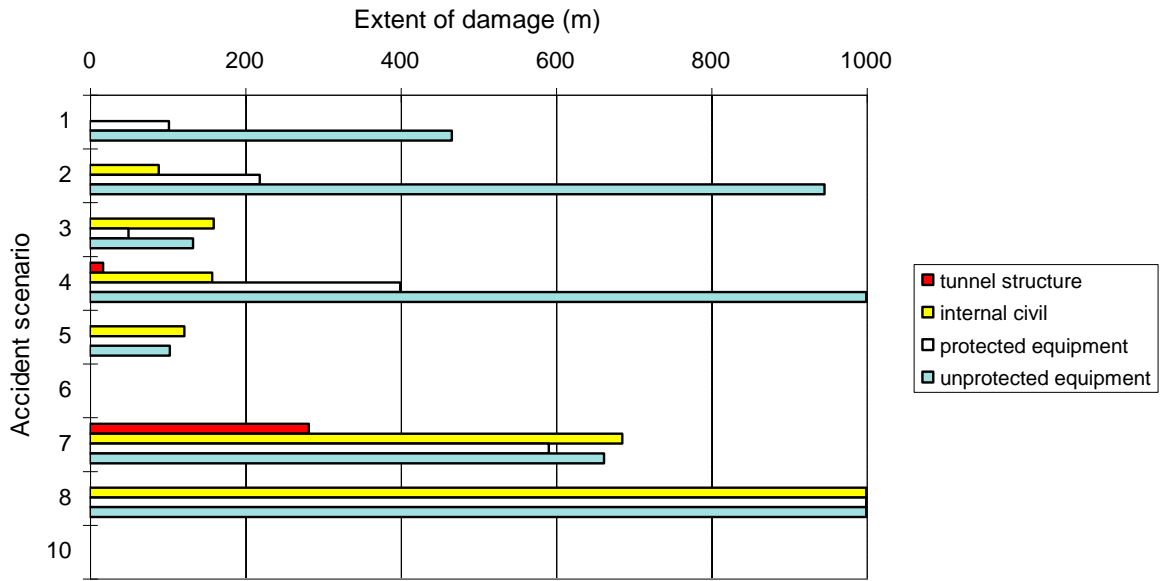


Figure 16 - Structural damage results for sensitivity case 10

ANNEX 3

Piston Effect in a tunnel

1. *Piston effect due to a single vehicle:*

$$P_1 = \frac{1}{2} * \rho_{air} * S_1 * Cx_1 * (v_1 - v_{air})^2$$

where: ρ_{air} is the air density (kg/m³),

S_1 is the front surface of the considered vehicle (m²),

Cx_1 is the drag coefficient of the considered vehicle,

v_1 is the vehicle speed (m/s),

v_{air} is the air velocity (m/s).

2. *Piston effect due to N_1 vehicles:*

$$P_{N1} = N_1 * P_1$$

where: N_1 is the number of vehicles simultaneously present in the tunnel:

$$N_1 = \frac{T_1 * L_{bore}}{v_1},$$

T_1 is the traffic density (veh/s) for the considered tunnel direction,

L_{bore} is the length (m) of the considered tunnel.

This can be written under the assumption that the vehicles have no influence on each

other draught: $P_{N1} = \sum_{i=1}^{N_1} P_i$

3. *Piston effect due to N_{LV} light vehicles and N_{HV} heavy vehicles:*

$$P = \frac{1}{2} * \rho_{air} * L_{bore} * \left[\frac{S_{LV} * Cx_{LV} * T_{LV}}{v_{LV}} * (v_{LV} - v_{air})^2 + \frac{S_{HV} * Cx_{HV} * T_{HV}}{v_{HV}} * (v_{HV} - v_{air})^2 \right]$$

This equation is derived from the preceding ones and takes account of the different types of vehicles in the traffic.

4. Air pressure in the tunnel:

$$\frac{P}{S_{bore}} = P_{dyn} * \left(\alpha + \lambda * \frac{L_{bore}}{Dh_{bore}} \right)$$

where: S_{bore} is the section (m²) of the considered tunnel,

P_{dyn} is the dynamic air pressure (Pa): $P_{dyn} = \frac{1}{2} * \rho_{air} * v_{air}^2$,

α is a singular pressure loss coefficient due to tunnel portals,

λ is a coefficient related to the tunnel surface mean roughness (and also the Reynolds number if they are small),

Dh_{bore} is the tunnel equivalent diameter (m): $Dh_{bore} = \frac{4 * S_{bore}}{P_{bore}}$,

P_{bore} is the tunnel perimeter (m).

$$\text{Thus: } \frac{P}{S_{bore}} = \frac{1}{2} * \rho_{air} * v_{air}^2 * L_{bore} * \left(\frac{\alpha}{L_{bore}} + \lambda * \frac{P_{bore}}{4 * S_{bore}} \right)$$

5. Calculation of air velocity:

When the air movement is entirely due to the traffic, one can write:

$$\left[\frac{S_{LV} * Cx_{LV} * T_{LV}}{v_{LV}} * (v_{LV} - v_{air})^2 + \frac{S_{HV} * Cx_{HV} * T_{HV}}{v_{HV}} * (v_{HV} - v_{air})^2 \right] = v_{air}^2 * \left[\alpha * \frac{S_{bore}}{L_{bore}} + \frac{\lambda}{4} * P_{bore} \right]$$

If one considers the following coefficients:

$$\alpha_{LV} = \left[\frac{S_{LV} * Cx_{LV} * T_{LV}}{v_{LV}} \right],$$

$$\alpha_{HV} = \left[\frac{S_{HV} * Cx_{HV} * T_{HV}}{v_{HV}} \right],$$

$$\beta = \left[\alpha * \frac{S_{bore}}{L_{bore}} + \frac{\lambda}{4} * P_{bore} \right],$$

then the preceding equation can be written:

$$\left[\alpha_{LV} * (v_{LV} - v_{air})^2 + \alpha_{HV} * (v_{HV} - v_{air})^2 \right] = \beta * v_{air}^2$$

The resolution of this level-2 polynomial equation gives the value for v_{air} corresponding to the searched piston effect.

ANNEX 4

PREPARING DATA SETS

1 Foreword

The use of the QRA in order to evaluate the risks along a route goes through different steps.

Initial steps are:

1. Collecting data,
2. Giving a structure to the data,
3. Input of the structure data,
4. Computations.

By giving structure to the data, we mean the making of decisions regarding the following questions:

- Time periods: How many time periods have to be chosen (Is there a touristical period ? Are the peak hours to be looked at precisely ?)
- Directions: Is it worth to separate directions A and B, or make a unique computation involving both directions simultaneously ?
- Sections: How is the route lay out to be finally set in the data ? Along each one of the segments, descriptive parameters are:
 - either constant no matter the time period and the direction,
 - or depending of the time period and the direction.
- Population description: 1 D or 2 D (Fortran program Rk-DG used in that latter case).

2 Preparing data

Figure 1 shows the data to be entered that are constant all along a route, but that can be change with time period and travel direction.

Figure 2 shows the data to be entered that change with segments.

Many data are needed. They are asked for by the dialog boxes. In order to have the user ready to input, these questions, it's better to have the answers ready and

corresponding data gathered and prepared on a blank sheet like those present in data_preparation.xls.

A way to prepare data is to have those sheets printed and use them to put down the different parameters.

3 Editing data

It is sometimes, useful to edit data that have been entered once the whole input file has been built and saved.

This has to be performed for 2 main reasons:

- Either because there were mistakes in the data input,
- Or because, it is more convenient to enter automatically data through the dialog boxes which propose the values that have been stored before and key in changes later. In order to help the user to do this, Figure 3 shows what data may be and must not be edited.

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
2	1) Data that are constant all along a route, but that can be modified as a function of time period and travel direction															
3	Route name shcomp_NORMAL															
4	Route description shcomp															
5	Average number of persons in a car		2													
6	Average number of persons in a HGV		1.1													
7	Average number of persons in a Bus/Coach		40	Consider fires for Non-DG HGV?				No								
8	HDGV traffic (veh/h)		10	Scen:	2	3	4	5	6	7	8	9	10	11	12	13
9	Proportion of each DG type in the whole for :			DG potentially leading to a large (100MW) fire (except	Propane 50kg	Flammable liquids in bulk (Motor spirit, diesel oil,...)	Fraction of flammable liqs potentially leading	Chlorine in Bulk	Propane in Bulk	Propane in Bulk	Propane in Bulk	Ammonia in Bulk	Acrolein in Bulk	Acrolein in Cylinder	liquefied CO2 in Bulk	
10	Ratio:			0.006	0.008	0.363	0.5	0	0.024	0.0236216	0.023622	0.015	0.002	0.002	0.013	
11	Remaining part:		0.568													
12	Period number:		1	Direction:				A								
13	Time ratio for this period		0.4													

Figure 1 : Data to be entered that do not change with segments, but may change with time period and direction (displayed with a colour coding on a fictitious example). On this example, these data are in yellow background.

	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
	Section #	Tunnel? (0=NO) (1=YES)	X (m)	Y (m)	Straight line (m)	User defined length (m)	Urban / Rural?	Rk-DG use?	Total traffic (veh/h)	HGV ratio (adim)	Bus / coaches Ratio (adim)	Light vehicles speed (km/h)	HGV/Bus speed (km/h)	Delay (s) for stopping approaching traffic	Number of lanes	First run: User defined or Default frequency ?	Accident frequency (/veh.km)	DG transport correction factor	Density of population (inhab/km ²)	Country
20																				
21	0	0	9500	9500	0	0			0	0	0	0	0	0	0		0	0	0	France
22	1	0	10100	9500	600	888	Urban	Sk	1000	0.09	0.01	120	80	120	3	2	9.73E-07	3.85E-01	1.00E+04	France
23	2	1	10100	10500	1000	0	Rural	Sk	1000	0.09	0.01	120	80	120	3	2	9.06E-07	1.00E+00	1.00E+04	France
24	3	0	10500	10500	400	0	Rural	Rk	1000	0.09	0.01	120	80	120	3	2	3.24E-07	1.00E+00	1.00E-17	France
25	4	0	10500	10500	0	0	Rural	Rk	1000	0.09	0.01	120	80	120	3	2	3.24E-07	1.00E+00	1.00E-17	France

Figure 2 : Data to be entered that change with segments (displayed with a yellow background colour coding on a fictitious example)

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
2	1) Data that are constant all along a route, but that can be modified as a function of time period and travel direction																				
3	Route name shcomp NORMAL																				
4	Route description shcomp																				
5	Average number of persons in a car 2																				
6	Average number of persons in a HGV 1.1																				
7	Average number of persons in a Bus/Coach 40																				
8	HGV traffic (veh/h) 10																				
	Scen:	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
	Proportion of each DG type in the whole for :		DG potentially leading to a large (100MW) fire (except	Propane 50kg	Flammable liquids in bulk (Motor spirit, diesel oil,...)	Fraction of flammable liqs potentially	Chlorine in Bulk	Propane in Bulk	Propane in Bulk	Propane in Bulk	Ammonia in Bulk	Acrolein in Bulk	Acrolein in Cylinder	liquefied CO2 in Bulk							
9	Ratio:		0.006	0.008	0.363	0.5	0	0.024	0.023622	0.023622	0.015	0.002	0.002	0.013							
10	Remaining part:		0.569																		
11	Period number:		1																		
12	Time ratio for this period		0.4																		
13	Direction:		A																		
19	2) Data that are modifiable as a function of the route, the time period and the travel direction																				
	Route characteristics	Section #	Tunnel? (0=NO, 1=YES)	X (m)	Y (m)	Straight line (m)	User defined length (m)	Urban / Rural?	Rk-DG use?	Total traffic (veh/h)	HGV ratio (adim)	Bus / coaches Ratio (adim)	Light vehicles speed (km/h)	HGV/Bus speed (km/h)	Delay (s) for stopping approaching traffic	Number of lanes	First run: User defined or Default frequency ?	Accident frequency (/veh.km)	DG transport correction factor	Density of population (inhab/km²)	Country
20		0	0	9500	9500	0	0			0	0	0	0	0	0	0		0	0	0	France
21		1	0	10100	9500	600	888	Urban	Sk	1000	0.09	0.01	120	80	120	3	2	9.73E-07	3.85E-01	1.00E+04	France
22		2	1	10100	10500	1000	0	Rural	Sk	1000	0.09	0.01	120	80	120	3	2	9.06E-07	1.00E+00	1.00E+04	France
23		3	0	10500	10500	400	0	Rural	Rk	1000	0.09	0.01	120	80	120	3	2	3.24E-07	1.00E+00	1.00E-17	France
24		4	0	10500	10500	0	0	Rural	Rk	1000	0.09	0.01	120	80	120	3	2	3.24E-07	1.00E+00	1.00E-17	France
25																					
26																					
27																					
28																					
29																					
30																					
31																					
32																					
33																					
34																					

Figure 3 : Data that may be edited, data that must not be edited (displayed with a colour coding on a fictitious example)

ANNEX 5

HOW TO CHOOSE DG TRAFFIC RATES

1 Foreword

The QRA assesses the risks along a route using different scenarios which imply different DGs (Dangerous Goods) which may be transported in bulk or packed in small quantities.

It was a necessity to limit the number of scenarios, and so the QRA is based on a set of only 13 scenarios.

Each one of scenarios 3 to 13 involves a specific DGs (**Table 1**), but one may consider those DGs as representative of other products able to produce the same sort of dangers.

Scenario #	Description	Mass concerned	Breach diameter (mm)	Release rate (kg/s)	DG Class	Danger Code	Classification code	N° ONU
1	HGV fire 20 MW (no DG)	-	-	-	-	-		
2	HGV fire 100 MW (no DG)	-	-	-	-	-		
4	Motor spirit pool fire	28 tonnes	100	20.6	3	33 & 30	F1 - II F1 - III	1203 & 1202
5	VCE of motor spirit	28 tonnes	100	20.6	3	33	F1 - II	1203
3	BLEVE of a 50kg LPG cylinder	50 kg	-	-	2	23	2F (flammable)	1965, 1978, 1011
7	BLEVE of an 18 tons LPG tank	18 tonnes	-	-	2	23	2F (flammable)	1965, 1978, 1011
8	VCE from an 18 tons LPG tank	18 tonnes	50	36	2	23	2F (flammable)	1965, 1978, 1011
9	Torch fire from an 18 tons LPG tank	18 tonnes	50	36	2	23	2F (flammable)	1965, 1978, 1011
6	Chlorine release from a 20 tons tank	20 tonnes	50	45	2	268	2TC (toxic corrosive)	1017
10	Ammonia release from an 18 tons tank	20 tonnes	50	36	2	268	2TC (toxic corrosive)	1005
11	Acrolein in bulk	25 tonnes	100	24.8	6.1	663	TF1 - I	1092
12	Acrolein in cylinder	100 litres	4	0.02	6.1	663	TF1 - I	1092
13	Liquefied CO ₂ in bulk	20 tonnes	-	-	2	22 (toxic aspect not taken into account)		1003, 1977

Table 1: List of the 13 scenarios and the DGs they involve

The scenarios were chosen because they were potentially dangerous either in the Open air or in tunnels or both.

That is the reason why class 2 (gases) is so highly represented (scenarios 3, 7, 8, 9, 6, 10, 13).

Class 3 is represented by scenarios 4 and 5.

Toxic liquids are represented by scenarios 11 and 12.

2 Correspondence

2.1 *The need for Simplifications*

On a route, it is difficult to get detailed information relative to the DG traffic.

When it is available, it is generally:

- For long periods and large areas, indications per class (ADR classes)
- For short periods on shorter routes, lists of observed identification tags (33 1203 for motor spirit).

The question is : how do we use that information in order to indicate the traffic rates that are needed in the QRA (cells E10:P10 of the sheets Route_Per?_Dir? in the files describing a case to be computed)?

Before we answer this, we want to state there is no way to do this “perfectly” because the assessment by the means of a set of 13 scenario of risk due to the thousands of different goods that may be transported is a rough and coarse simplification. Similarly, the correspondence between the observed DG traffics and the rates to be chosen in order to fill in data files will be a coarse simplification of reality.

2.2 *Principles for the correspondence*

The way the risk is assessed in the QRA may be summarised as : compute fatalities and determine corresponding yearly frequencies.

The fatalities are computed using models which are based primarily on:

- physical modelling,
- physiological response (taking into account possibilities to escape or find a shelter).

Because of that, it seems logical to assimilate to the DGs involved in the scenarios, others that may lead to similar physical phenomena and have similar modes of action on populations and road users.

The idea is to keep the severity calculated for the scenario but consider the yearly frequency to get it is not only due to the traffic of the specific DG which has been modelled but also others who might lead to similar phenomena.

2.3 Proposal for the correspondence

As already stated, the correspondence is a simplification and therefore may be done in different ways. We propose hereafter in **table 2** a way to do it.

Cell	DG directly associated with a scenario	Types of DG correspondence to base traffic rate upon	Scenarios
E10	DG potentially leading to a large (100MW) fire (except liquids)	rough amount of DGs that are combustible (roughly class 4)	2
F10	Propane 50kg	class 2F , part in cylinders	3
G10	Flammable liquids in bulk (Motor spirit, diesel oil, ...)	class 3	4
H10	Fraction of flammable liqs potentially leading to VCE (excl diesel oil)	Motor Spirit (3F1 does not seem to be a good correspondence, it is wiser to use danger code 33)	5
I10	Chlorine in Bulk	Chlorine (and other very toxic gases with IDLH <= 50ppmv) in Bulk	6
J10	Propane in Bulk	class 2F , part in bulk	7, 8, 9
M10	Ammonia in Bulk	class 2T (TF, TC, TO, TFC, TOC) transported in bulk except Chlorine and very toxic gases	10
N10	Acrolein in Bulk	class 6 , part in bulk	11
O10	Acrolein in Cylinder	class 6 , part in cylinders	12
P10	liquefied CO2 in Bulk	class 2 gases which have not been taken into account already because flammable or toxic	13

Table 2: Types of DG correspondence to base traffic rates upon. In column cell, the notations are the ones used in the sheets of the data files : Route_Per1_DirA, ... , Route_Per3_DirB

It appears that some classes are totally absent from the correspondence, namely classes 1, 5, 7 and 8.

In those classes , DGs are able to cause severe damage: explosives of class 1, HF in class 8 for instance but cannot be taken into account so far with the model.

On the other hand, it is possible to know what scenarios have to be computed and which one may be skipped: if there is no transportation of chlorine or very toxic gases in bulk, scenario 6 may be skipped.

The input of these DG traffic rates is operated when the dialog box shown by **figure 1** is displayed

The dialog box is titled "User defined DGi/DG traffic - Form 1/1" and contains the following text and input fields:

Enter the proportion (ratio) of each DG type in the whole DG traffic for the current period

Flammable liquids in bulk (Motor spirit, diesel oil, ...):	0
Fraction of flammable liquids that can potentially lead to a VCE (includes motor spirit but excludes diesel oil):	1
Propane (flammable liquefied gases) in cylinders:	0
Propane (flammable liquefied gases) in bulk:	0
Chlorine (Rather severe toxic gases) in bulk:	0
Ammonia (Toxic gases) in bulk:	0
Acrolein (Toxic liquids) in bulk:	0
Acrolein (Toxic liquids) in cylinders:	0
Compressed CO2 (non flammable non toxic gases) in bulk:	0
	0
	0
	0
DG potentially leading to a large (100MW) fire (except liquids):	0
Others (Potentially leading to at least a 20MW fire):	

WARNING: The scenarios are supposed to occur on full loaded DG-HGVs. Slightly loaded DG-HGVs are to be removed when entering the proportions of each DG types to consider for further calculations

Buttons: Quit, Cancel, Calculate, OK

Figure 1: Dialog box displayed for the input of the DG traffic rates

ANNEX 6

GRAM VERSION 4.04

INSTALLATION AND BASIC TESTS

1. INSTALLATION

1.1 *Compatibility*

1.1.1 MS-WINDOWS

The version 4.04 of the GRAM is compatible with the 32 and 64 bits versions of:

Ms-Windows 7

Ms-Windows 8

Ms-Windows 8.1

Ms-Windows 10

The last version of Ms-Windows whose compatibility has been checked is:
W10 Professional Version 20H2 / 19042.572

1.1.2 MS-OFFICE

The version 4.04 of the GRAM is compatible with the 32 and 64 bits versions of:

Ms-Office 2007

Ms-Office 2010

Ms-Office 2013

Ms-Office 2016

The last version of Ms-Office whose compatibility has been checked is:
Ms-Office 2016 build 12730.20352

The last version included:

Excel 2016 MSO (16.0 Version 10.0.19042 build 12730.20342) 64 bits

VBA 7.1.1097 Form3: 16.0.12730.20144

It is important to note that Microsoft Excel has to be installed with its full VBA capabilities. The macro-commands included in the software package are using a wide range of VBA instructions that can cause failure at each run of the QRA model if VBA is not fully operational.

1.2 Installation

To install the 4.10 version of the QRAM just follow the steps detailed in the Annex 7 of the User Guide.

This should need administrator's privilege.

2. Functions.xla

2.1 Copying functions.xla

The software uses a certain number of additional private functions (and subroutines) which are stored in file " Functions.xla ". This file must imperatively be present in the root C:\ (the partition where Ms-Windows system is present).

An installation will copy the file functions.xla in directory C:\

But if you have doubts, you can check with the file explorer the presence of file C:\Functions.xla (it may keep a Read/Only status). If this file is missing, it means the installation executable was denied the right to create the file on C:\. Ask the help of your system administrator.

2.2 Declaring functions.xla as Add-in

If no version of the QRAM has never been installed on the computer, to make things work properly, an initial declaration of these additional functions as Ms-Excel "add-in" is needed (this is detailed in the Ms-Office tuning guidance available as stand alone PDF files named "[Excel-20xx_Tuning.pdf](#)" where **xx** is 07, 10, 13, 16 accordingly to the Ms-Office release).

The general procedure may be resumed as follows:

- open Ms-Excel,
- select menu and sub menus " File "; " Options "; " Add_ins... "; " Go / Browse "
- select file C:\Functions.xla and click OK,
- close Ms-Excel,
- re-open Ms-Excel.

2.3 Checking functions.xla is an Add-in

If you want to check that the installation has been properly done, simply use the file "[Test functions as addin](#)" located in directory "installation_test" (just click on it in your file manager).

3. UK / British Regional setting

Setting the regional environment

This part concerns only users whose computer is configured in a non-UK environment. To make the QRAM operational, they have to install a British/UK environment (this does not concern the keyboard). This British/UK environment must be active every time the QRAM software is used.

With this setting, the default decimal separator is a dot symbol (.) – not a comma (,) like for many European users.

The way to achieve this is slightly different with the various versions of Ms-Windows.

It has to be performed in the "Regional Settings" item of the control panel. The thumbnail "Country" of the "Regional Settings" item contains a line that allows the user to change the country of reference for some settings. Put it to "English (GB)" or "English (UK)".

But that should not prove sufficient with recent operating systems, because encryption methods are country related. In case of difficulties linked with encryption methods, you will have to change to "English UK" (UK as default setting) in the Advanced Options if there are any. This should need administrator's privilege.

With all Ms-Windows versions, you may create several user accounts, but with elaborate versions of Ms-Windows, the regional settings may be different from an account to another. So, if your version is an elaborate one, it is possible to have an account with UK settings dedicated to the QRAM and other accounts keeping other country settings.

Checking the regional environment

Since, this is troublesome, a possibility to easily check that the QRAM is launched in a UK environment has been added. To do so, just open with Ms-Excel the small file "[liste_prevert.csv](#)" located in directory " installation_test" (just click on it in your file manager).

This will allow to check that the regional settings are tuned as they should.

File "[Use_of_prevert_csv.pdf](#)" located in the same directory explains more precisely what you can check with it and how to do it.

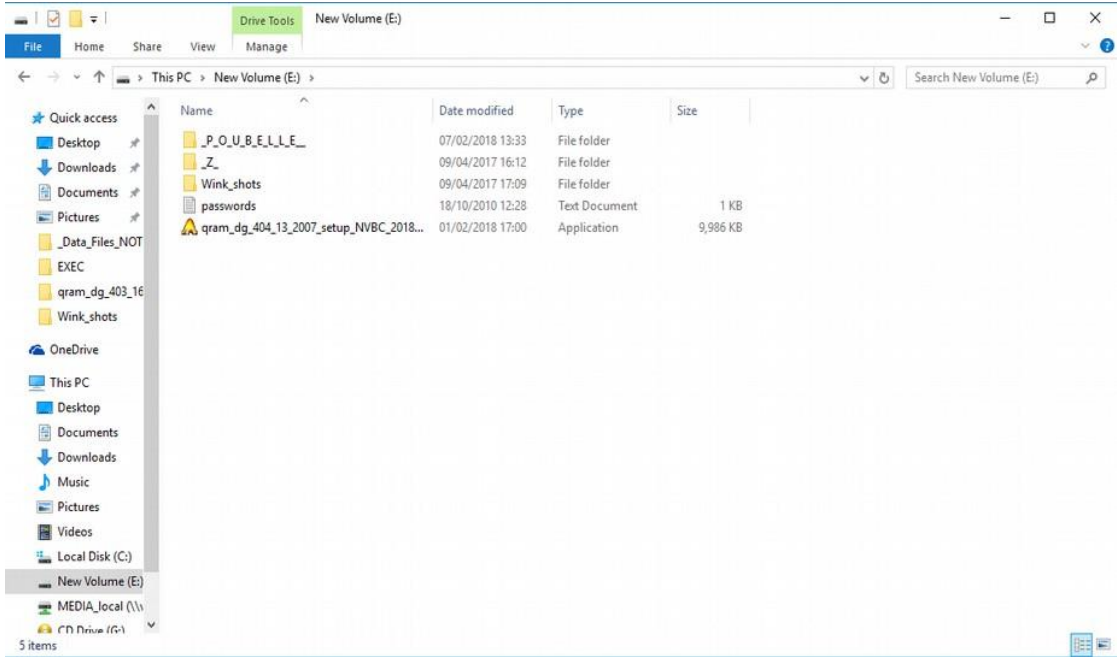
ANNEX 7

GRAM 4.xx INSTALLATION HOWTO

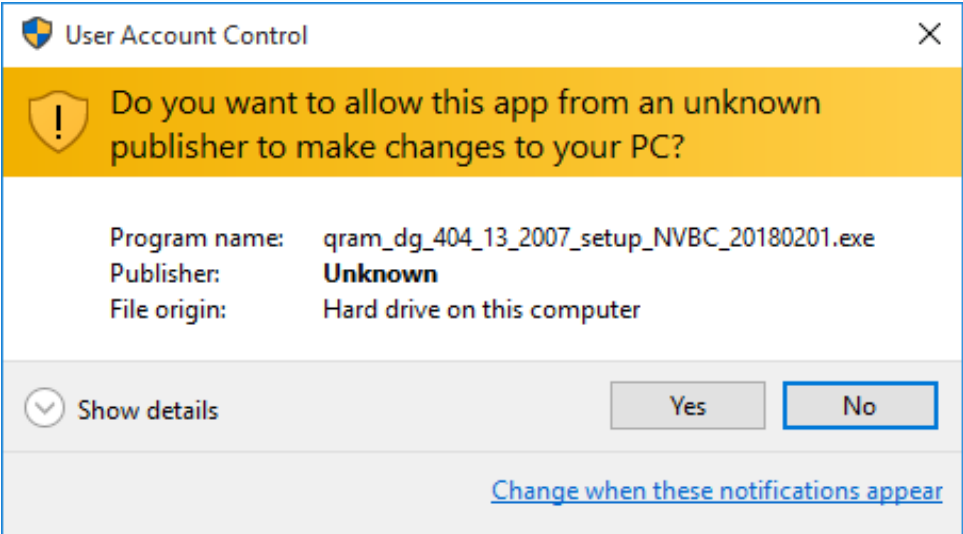
Since its version 4.04 of April 2018, the installation of the Quantitative Risk Assessment Model (QRAM) is always performed by an executable file with the same questions and messages issued all along the process and the need to answer them similarly.

The only differences due to the QRAM itself are the evolution with each version of the installation file name, the version number in the message boxes and possibly, the content of the ReadMe file displayed at the end. Other differences might arise from the Operating System (Windows 10 Pro in the following figures).

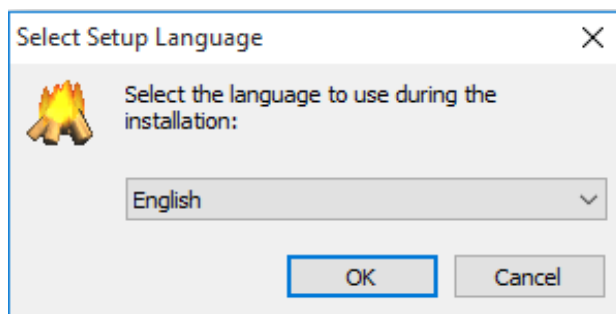
Anyway, this Annex written initially for the installation of Version 4.04 holds good for later versions 4.xx of the QRAM.



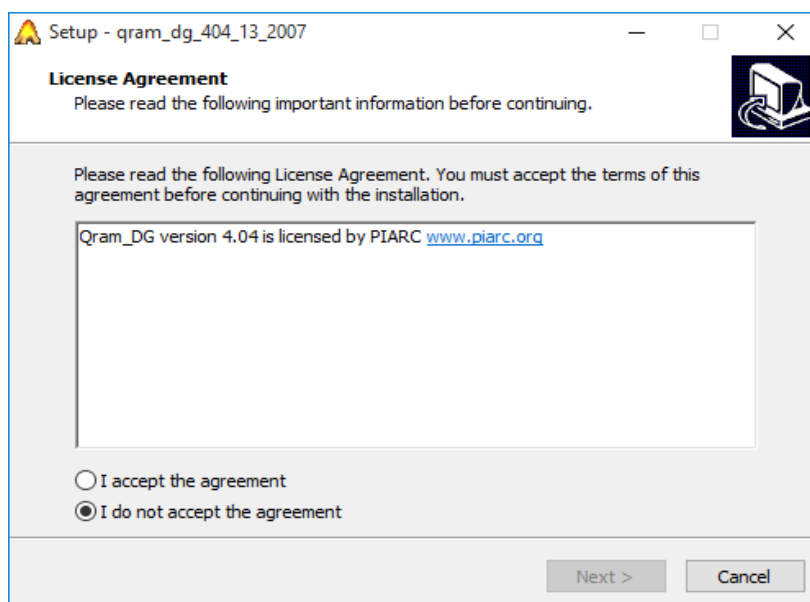
1) In the file explorer, click on the QRAM installation executable file in the figure above: qram_dg_404_13_2007_setup_NVBC_20180201.exe (for version 4.04)



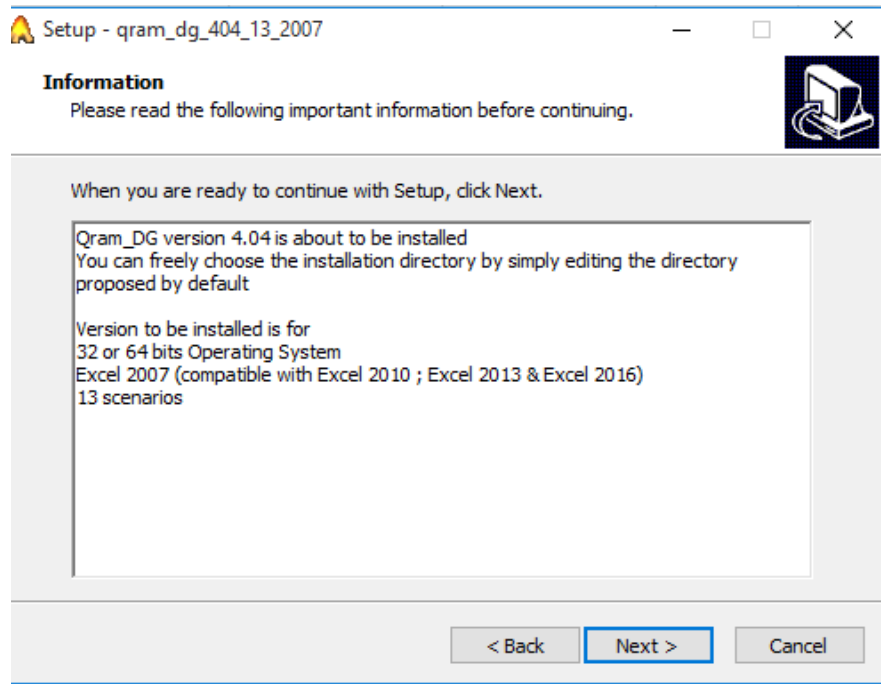
2) Click « YES »



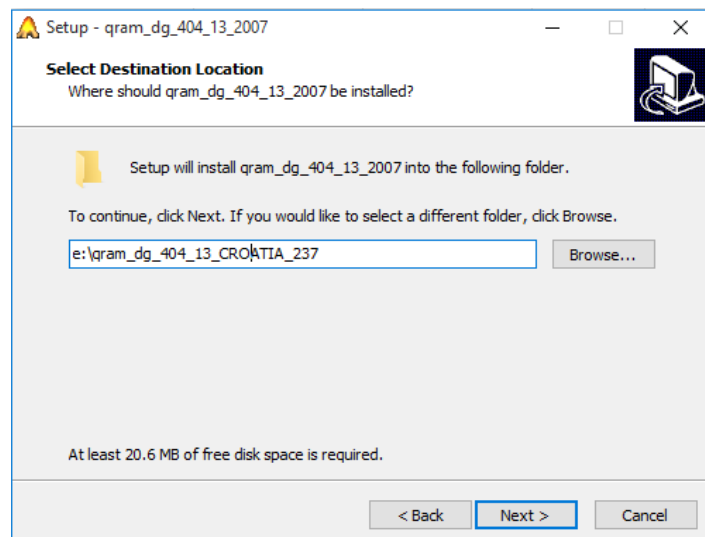
3) **Select the installation language « English » or « French »**



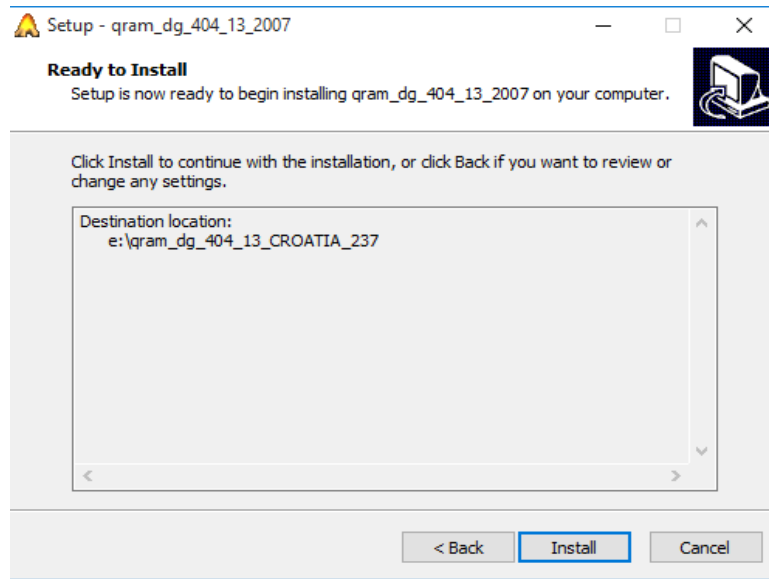
4) **Select « I accept » and then click « NEXT »**



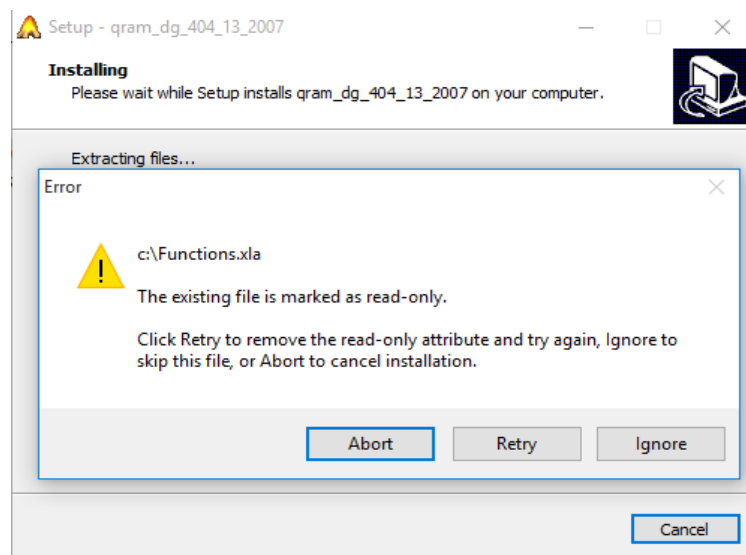
5) **Information displayed at this stage**



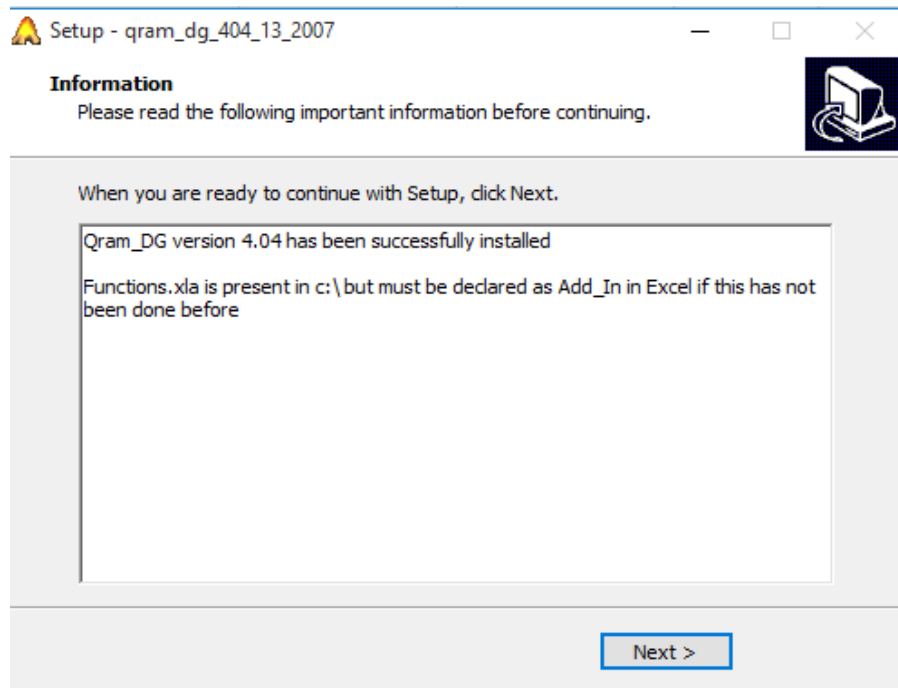
6) **Edit the proposal you will find in the dialog box and choose freely the location and name of the installation directory, but do not use an already existing directory.**



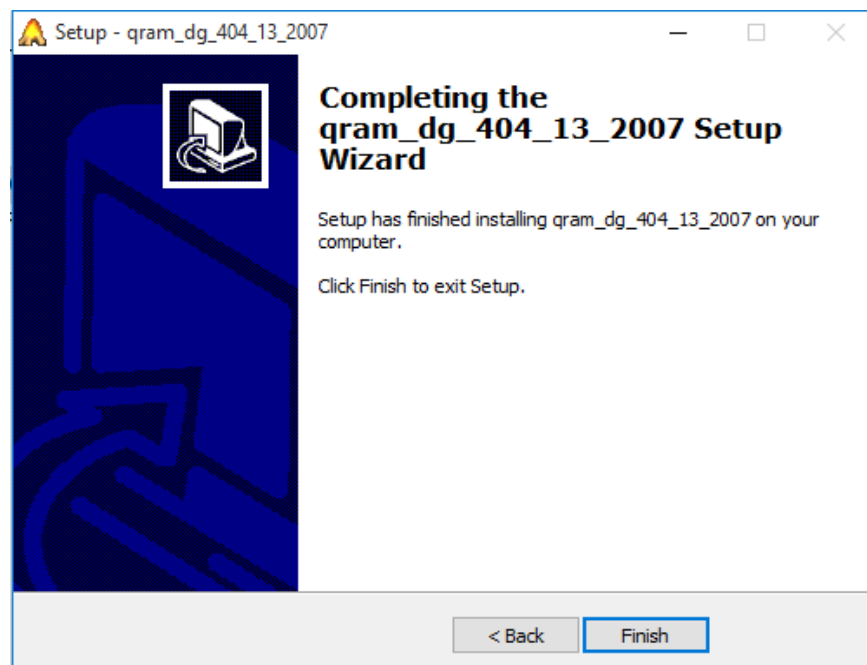
7) **Information displayed at this stage**



8) **You get this warning message only if the file [c:\functions.xla](#) already exists. If so, click « **Retry** » as many times as needed.**



9) **Information displayed at this stage**



10) **Click « Finish »**

A Readme file is displayed that gives some initial basic information about the use of the QRAM.

ANNEX 8

ADR COMBINATION TOOL

When there is a route with a tunnel and an alternative route, the ADR category A corresponds to the case where all DG (Dangerous Goods) transports are allowed in the tunnel. The choice of a non-permissive ADR category (B to E) for the tunnel decreases the risk due to the DG traffic for the tunnel route, but, increases it on the alternative route where DG traffic that are not allowed on the tunnel route would pass.

The only way to evaluate the impact of the category choice on the global risk due to the DG traffic is to add the risks on both routes.

This tool adds the risks on 2 routes if the QRA has been previously used for each one of them. The 2 output files issued from the previous QRA calculations have to be placed in the directory of this tool.

There is a risk to perform a combination of the 2 output files which makes no sense, as will be explained below.

So to check that the combination makes sense, this tool performs a certain number of tests.

These tests are meant to help avoiding mistakes in the use of combination tool, but it isn't guaranteed that these tests would avoid all possible mistakes.

Figure 1 shows the sheet displayed when the tool is opened.

The user has to fill in the cells with a pale blue background and cannot change cells with a yellow background.

For instance, the directory in which this 'ADR_combination_tool' is located called 'work directory' is automatically written by the tool on line 6.

The user has to indicate the name of the output file of the tunnel route in cell F10 of Figure 1, and the name of the output file of the open-air route in cell F11.

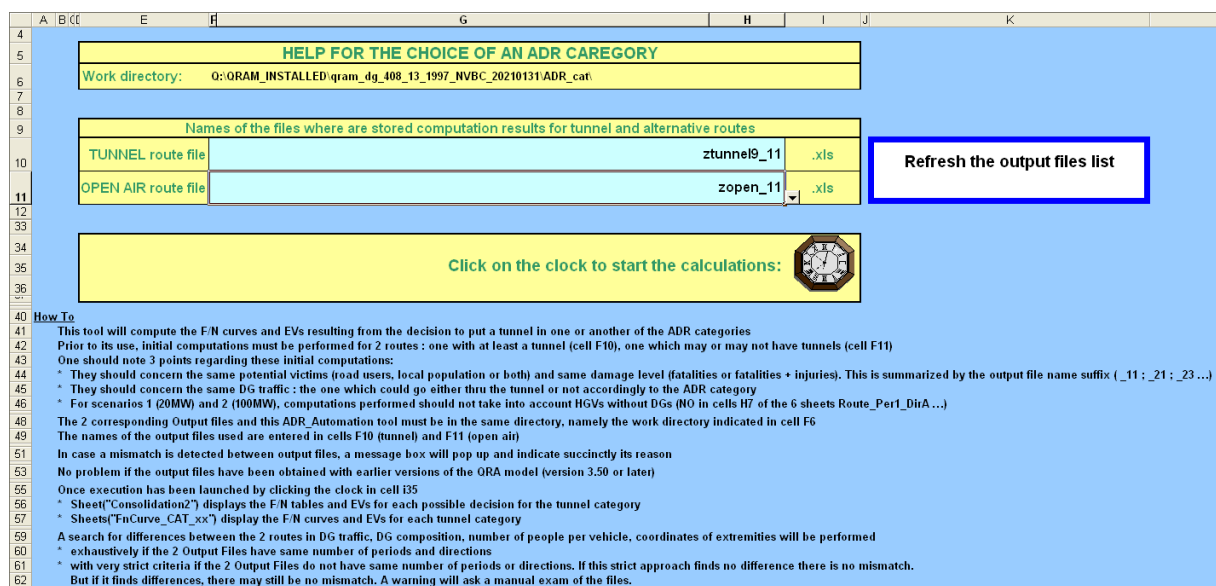


Figure 1 View of sheet displayed when the tool is launched

A list of the available output files found in the ‘work directory’ (mentioned in cell F6) will pop up for the choice (Figure 2).

If the user does not find the output files he is looking for in the list and adds them while this tool is open, they will not appear in the list as long as the ‘Refresh button’ of cells K10:K11 has not been clicked.

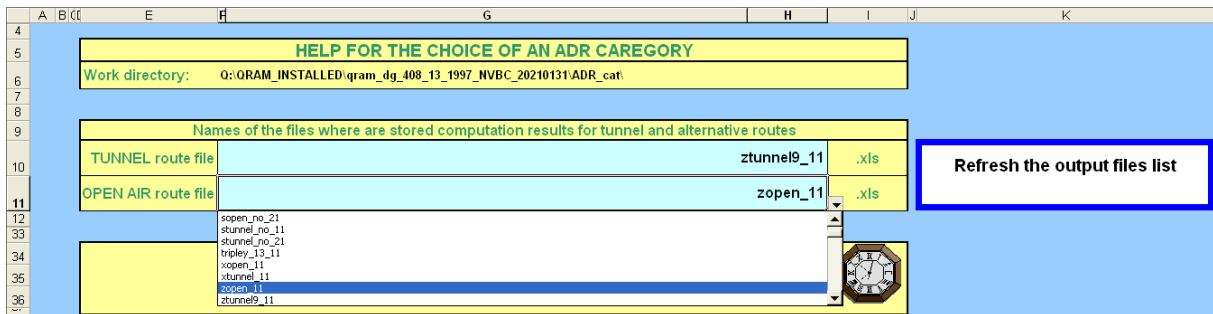


Figure 2 View of the list of proposed output files present in the work directory

The calculations are launched by clicking the clock in cell i35.

If the choices made in cells F10 and F11 for the output files are inconsistent, a message will be displayed and the execution halted.

Choices are inconsistent if:

- File in cell F10 is related to a route with no tunnel
- Cells F10 and F11 refer to same file
- Suffixes (_11; _21; ...) of the 2 output files are not identical (which means the nature of risks calculated is not the same)
- Non-DG HGVs are taken into account in one of the risk assessments (Figure 3)
- For the 2 routes, selected scenarios are different.

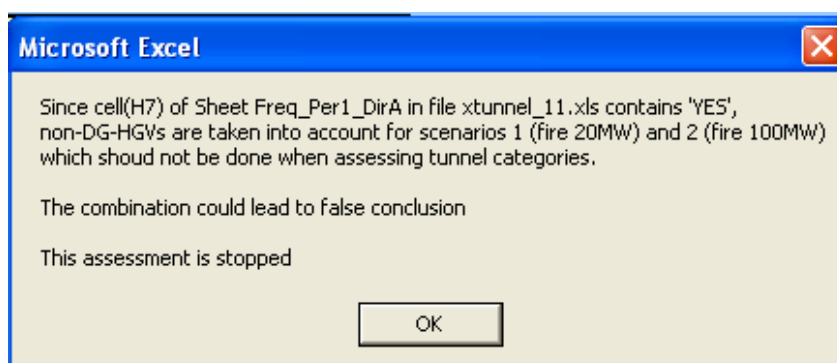


Figure 3: Example of a warning with stop of the assessment

If the choices are consistent, tests will be performed to check that combining the 2 output files makes sense.

If both output files have same number of periods and directions, these tests will be exhaustive and check that:

- each period has same duration
- for each period and direction, the number of people in a vehicle¹, the DG traffic rate, the DG traffic composition, route extremities co-ordinates are identical on both routes.

If no difference is found, no message will be displayed until the calculation is finished and the F/N curves displayed.

In case, differences are found, a message will be displayed (see Figure 4a).

If number of periods and/or directions are different for the 2 routes, it is impossible to perform automatic meaningful tests.

In that case, an advice to the user will be displayed (see Figure 4b).

When warned (see Figures 4a and 4b), the user will still have the possibility to make calculations and build F/N curves (see Figure 5).

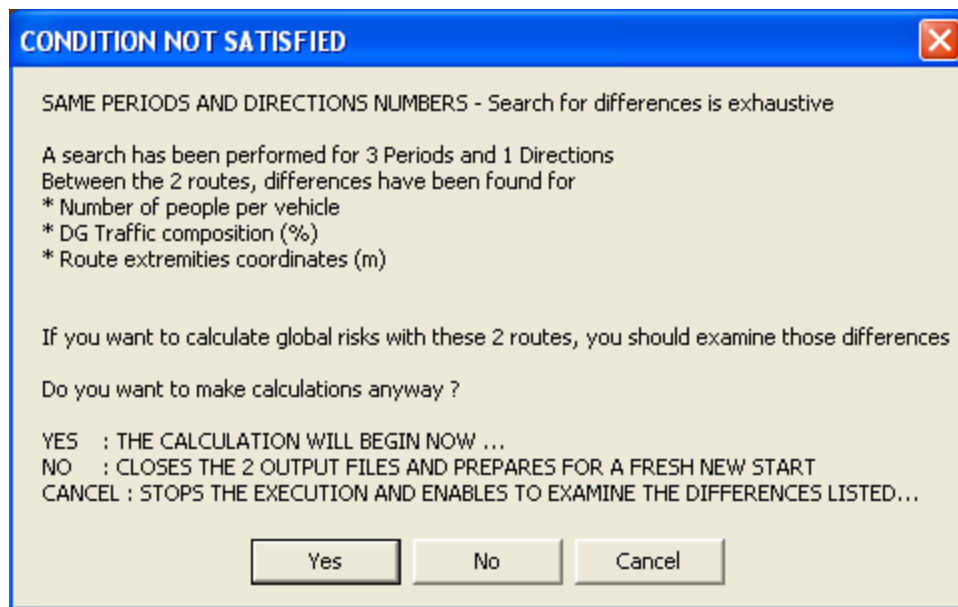


Figure 4a: Example of a warning and choice proposed to the user in case both routes have same number of Periods and Directions

1 The number of people in a DG-HGV should be the same on both routes. But, for the rest, these numbers are likely to be different. The user will get the warning about the number of people in the vehicles, check them, see if the differences are logical, and then go on with the combination and produce the F/N curves.

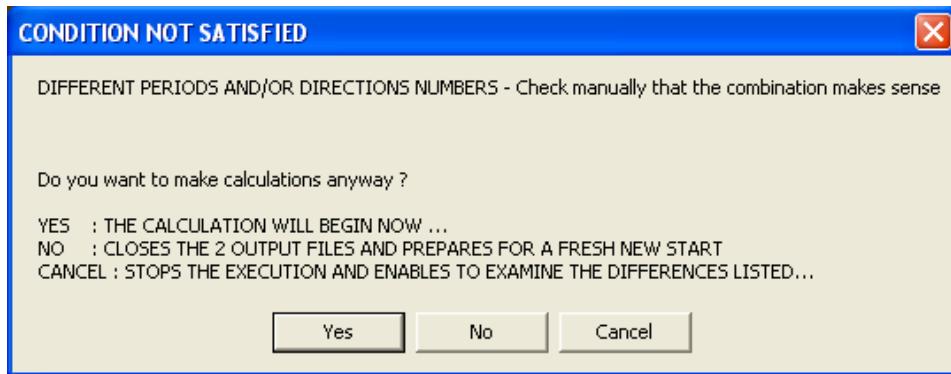


Figure 4b: Example of a warning and choice proposed to the user in case both routes do not have same number of Periods or Directions

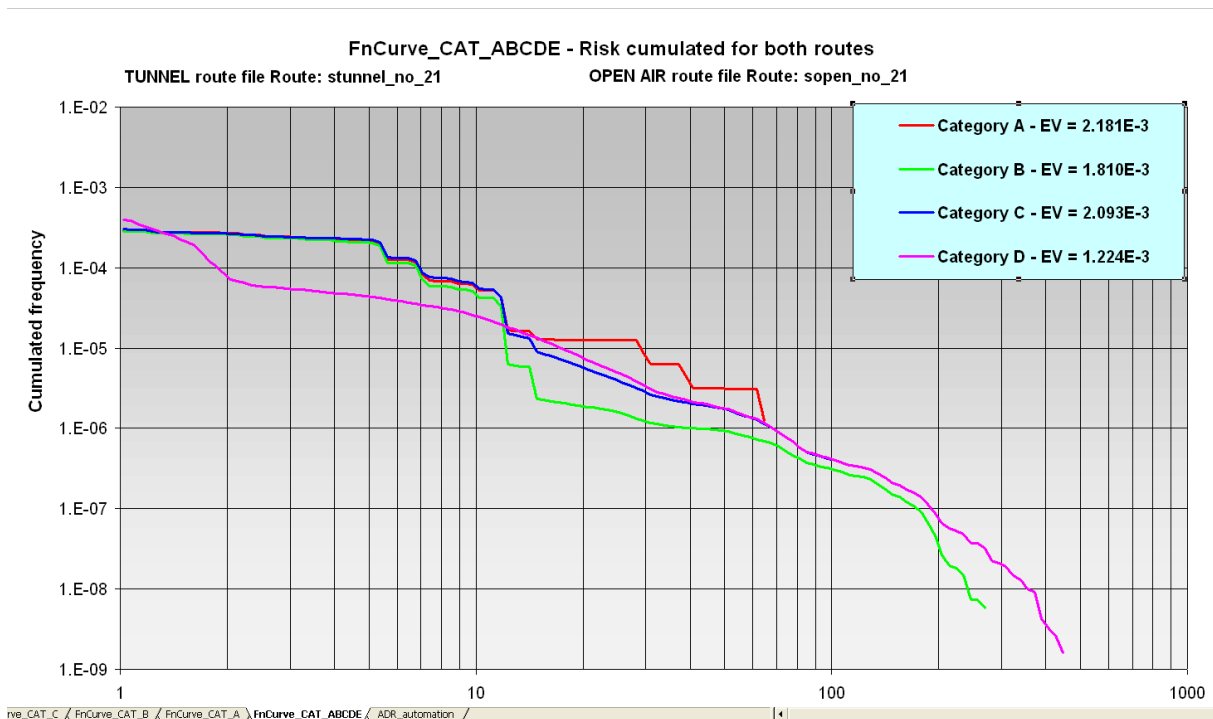


Figure 5: Example of build F/N curves with display of the names of the 2 routes and calculated EVs

ANNEX 9

ADDITIONAL INFORMATION & USER ADVICE

The purpose of this annex is to assist in the use of the QRA for case studies, and in particular to advise the user on the input data to enter in the QRAM (local and default data). These topics are successively addressed in the annex:

- Advice for data collection and choice of data
- Advice for using scenarios 11 and 12 for alternative toxic substances
- Advice for empty vehicles and unidentified dangerous goods
- Advice how to distinguish categories E and D (without using the DGQRAM model) for countries that don't use scenario 1 and 2

Advice for data collection and choice of data

The proper choice and setup of input data is vital for the quality of the risk assessment results. As described in section 20 of the User's Guide, the user will be proposed some default values for specific input data when local data are not available or of insufficient quality and reliability, but no default values will be provided for input that is very route-specific, such as:

The description of the routes:

Necessary route information that must be known by the user for the proper use of the model are the geometrical data of the route (segment length, spatial separation of driving directions, orientation of segments), traffic characteristics of the route (number of driving lanes and speed limits for cars and HGV, respectively) and whether a section of the route is a tunnel section or an open-air section.

The global traffic and its composition:

First of all, the user has to decide over how many time periods the traffic volume and population should be distributed. Three options exist:

- 3 periods of time (normal, quiet, peak)
- 2 periods of time (normal, quiet)
- 1 period (normal)

It should be noted that the name of the period has no influence on the results. It's just recommended to choose the name of the period in accordance with the reality of the parameter's variations, in order to avoid possible mistakes.

The above choice depends on the quality of the available traffic and population data as well as the actual hourly (yearly) distribution of the traffic flow. In case only AADT values are known for the route under investigation, the choice of one period and the declaration of 1/24th of the AADT for the hourly traffic of the normal traffic period is possible but would lead to an imprecise assessment. In this case, it's always more appropriated to use a characteristic daily traffic distribution and apply it to the AADT traffic.

It is therefore suggested to work from the diurnal traffic distribution, if possible. The diurnal traffic distribution can be separated in either two- or three-time periods, depending on the presence of a pronounced traffic peak within the daily traffic distribution. Once the partitioning has been defined, the average hourly traffic volume of each partition as well as the time ratios of the respective partitions need to be calculated and used as input parameters. This should be done for each driving direction independently, if possible.

In addition to the traffic volume, the same time-period partitioning is used for the input of population densities. Therefore, both aspects – variation of traffic volume and variation of population density – must be taken into account when the time periods are defined. The number and duration of each time period selected should be consistent with population movements, e.g. different occupancy of residential and business areas and the population that is leaving or coming to a specific area during the selected time periods.

Usually the time periods quiet, normal and peak correspond to the time of day, with the quiet period referring to night time, the normal period referring to daytime and the peak period referring to morning- and late afternoon hours where the majority of the commuter traffic happens.

However, alternatively to the day and night time separation, also the partitioning of traffic volume (and population density) with respect to seasonal variations may be applicable, for example for routes in touristic resorts with a high seasonal activity. In this case, the quiet period could correspond to the night time, the normal period to the day except touristic period, and the peak period to the day during touristic period.

If a time separation alternative to day/night is used, the assumed distributions for road user and local population (compare Table 14 of Annex 1) reflecting the location of persons inside or outside buildings or vehicles must also be adapted. This can only be done by an expert user.

In any case, only periods when DG vehicles are allowed to travel should be considered, which may, for example, lead to the exclusion of weekends and public holidays if local regulations dictate it.

The global DG traffic rate:

In addition to the traffic flow of all vehicle types, also the DG-HGV (and, though less important, the overall HGV traffic) must be known. Ideally, the DG-HGV traffic (and maybe the overall HGV traffic), in terms of vehicles per hour, is known separately for each of the defined time periods. This data can be obtained, for example, if diurnal traffic distributions are known for each vehicle type (which is the case when a DG-counting is carried out).

If only the share of DG-HGVs and overall HGVs on the total traffic is known, the DG-HGV traffic can be obtained by multiplying the share of DG-HGVs and the overall hourly traffic of the respective time period. Often, the share of DG-HGVs is known only with respect to the overall HG traffic. In this case the DG-HGV share (on the HGV traffic) as well as the overall HGV share (on the total traffic) are multiplied with the hourly traffic volume of the respective time period.

The DG composition

Default values are presented for the proportion of each DG type in the DG traffic. However, this distribution may differ significantly according to the route under investigation (e.g. according to the local industrial environment), and this strongly influences the resulting risk and consequently the result of the risk assessment. This is in particular the case, if absolute assessment criteria are used or the absolute risk values are going to be interpreted. Therefore, it is highly recommended to know and use the route-specific DG composition according to a counting, or at least the DG composition on the regional level.

The way the DG composition needs to be specified in the software is tailored to the 11 DG scenarios (scenario 3 - 13). However, the DG transport data, usually available, is given with respect to UN numbers and Hazard Identification numbers. An assignment table exists to obtain the necessary input format.

The following table allows to determine the share of the identified DG vehicles to which one or more scenarios have to be associated, according to the hazard code on the orange plate of the vehicle, or in the absence of such a code, according to the hazard labels fixed to the vehicle, and according to the type of container (tank, cylinder or other).

In order to draw up this table, all the ADR danger codes were analysed, and for each of them and according to the above-mentioned parameters, one or more QRA scenarios were associated. This association was made with regard to the physical and chemical properties of the products and the quantities involved. Since the variety of danger codes (about 100) is larger than the 13 QRA scenarios, it appeared in some cases (minority) that it was possible to associate either with a scenario that was slightly more serious in terms of consequences (majoring) or with a scenario that was slightly less serious (minoring). In these few cases, the majoring scenario was systematically retained in a conservative approach.

Finally, this table is an aid for the association between the DG-HGV and the QRA scenarios. When a counting has been made, the exact nature of the products transported is known, so it is important to ensure that the association between these products and the scenarios reflects the characteristics of the product.

To illustrate this on an example, hazard codes 43 or 44 or 446 have been associated with pool fire scenario 4 (conservative approach). If it turns out that the products transported (depending on their nature and/or quantity) are more likely to lead to a less violent phenomenon than a motor spirit pool fire, then scenario 2 (100MW fire) should be chosen.

The user reports on the last line the total number of DG vehicles counted in column n^o4 (Σ) as well as the total number of DG vehicles associated to each scenario (i=3 to 13), by summing up the number of DG vehicles (Σs_i) appearing on the lines where a cross (x) appears in the column of the scenario considered.

The ratio of dangerous goods of each type among the global DG traffic must be filled in the following way in the data entry interface:

User defined DGi/DG traffic - Form 1/1

Enter the proportion (ratio) of each DG type in the whole DG traffic for the current period

Flammable liquids in bulk (Motor spirit, diesel oil,...) :	<input type="text" value="0"/>	$\frac{\Sigma s_4}{\Sigma}$
Fraction of flammable liquids that can potentially lead to a VCE (includes motor spirit but excludes diesel oil):	<input type="text" value="1"/>	$\frac{\Sigma s_5}{(\Sigma s_4 + \Sigma s_5)}$
Propane (flammable liquefied gases) in cylinders:	<input type="text" value="0"/>	$\frac{\Sigma s_3}{\Sigma}$
Propane (flammable liquefied gases) in bulk:	<input type="text" value="0"/>	$\frac{\Sigma s_7}{\Sigma}$
Chlorine (Rather severe toxic gases) in bulk:	<input type="text" value="0"/>	$\frac{\Sigma s_6}{\Sigma}$
Ammonia (Toxic gases) in bulk:	<input type="text" value="0"/>	$\frac{\Sigma s_{10}}{\Sigma}$
Acrolein (Toxic liquids) in bulk:	<input type="text" value="0"/>	$\frac{\Sigma s_{11}}{\Sigma}$
Acrolein (Toxic liquids) in cylinders:	<input type="text" value="0"/>	$\frac{\Sigma s_{12}}{\Sigma}$
Compressed CO2 (non flammable non toxic gases) in bulk:	<input type="text" value="0"/>	$\frac{\Sigma s_{13}}{\Sigma}$
	<input type="text" value="0"/>	
	<input type="text" value="0"/>	
	<input type="text" value="0"/>	
DG potentially leading to a large (100MW) fire (except liquids):	<input type="text" value="0"/>	
Others (Potentially leading to at least a 20MW fire):	<input type="text"/>	

WARNING: The scenarios are supposed to occur on full loaded DG-HGVs. Slightly loaded DG-HGVs are to be removed when entering the proportions of each DG types to consider for further calculations

Quit Cancel Calculate OK

Handling of ADR class 1

Danger codes of substances belonging to ADR class 1 are not explicitly included in the above table. In most cases, the number of vehicles transporting explosive substances of class 1 on an investigated route are insignificant. If, however, a significant amount of such transports is found in the DG traffic count, it is recommended to check for the source of these transports. In some cases, the documented transport can be related to temporary circumstances, the construction of a nearby tunnel, for example. If the documented ADR class 1 transports can be related to such a temporary characteristic, it should not be taken into account in a risk assessment, which usually aims to represent the long-term risk of an investigated route rather than the short-term risk of the actual observation period.

However, if a significant amount of ADR class 1 transports occurs on a regular long-term basis on the investigated route, DG-QRAM can be used to provide a very rough risk estimate even though no explicit scenario for explosives is available. Instead, the of ADR class 1 DG transports are associated to the scenarios 2, 3, 4 and 7 according to the following relation:

ADR subclass 1.1 → scenario 7/8/9 (Propane in bulk)

Substances of this subclass have a mass explosive hazard and can therefore have similar effects to a BLEVE scenario of a gas tanker in terms of the total energy release within a short time.

ADR subclass 1.2 and 1.3 → scenario 3 (Propane in cylinder)

Substances of this subclass do not have a mass explosive hazard but can lead to smaller explosions. I. e., they possess projection hazards and minor explosion hazards, respectively. They can therefore be compared to the small BLEVE scenario.

ADR subclass 1.4, 1.5 and 1.6 → scenario 2 (Flammable liquids in bulk)

Substances of this subclasses either do not have a mass explosive hazard and/or are very unlikely to explode, even in the presence of a fire. These substances are therefore associated with the 100MW HGV fire scenario rather than any explosive gas scenario with a significant conditional probability.

The resulting risk estimates, however, must be interpreted with great care, as they have to be understood as very rough order-of-magnitude estimates. Even though the physical properties of the associated gas-explosion- and fire scenarios may be quite comparable to the explosive scenarios, the conditional probabilities of these scenarios may differ significantly from the conditional probabilities of ADR class 1. Therefore, the described approximation is better suited for a comparative risk assessment approach, where the uncertainty of the conditional probabilities is the same on the tunnel route and the alternative route.

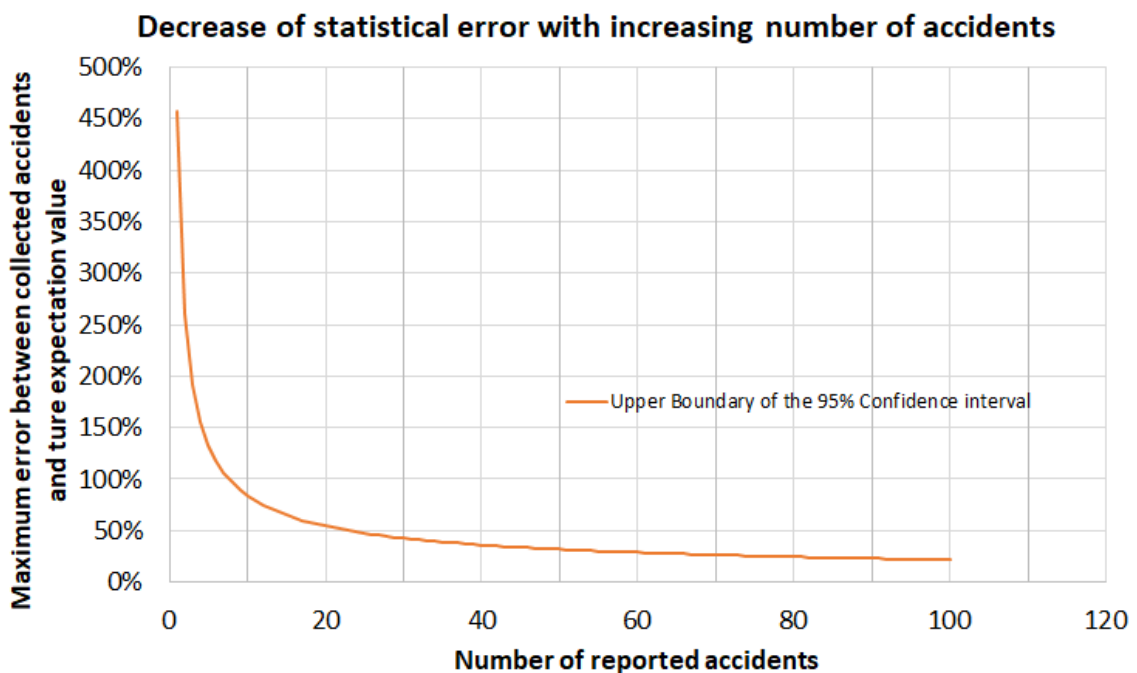
Accident rates

The accident rate of heavy-good vehicles is a crucial input parameter in the QRA model. Accident rates are not mentioned as specific input in section 20 of the User's Guide. However, the accident rate on the considered route may differ from the national default value due to specific route characteristics. Furthermore, default values may not exist for the country of the route under investigation. Therefore, it is highly recommended to collect incident and corresponding traffic data from the considered route or the associated part of the road network and to calculate specific accident rates, at least for comparison with the national values.

To calculate the specific accident rates, the number of accidents on a defined part of the road network as well as the associated kilometrage (traffic flow x length of the respective route), have to be collected over a certain time period.

The accident rate is then calculated as the ratio between number of accidents and associated kilometrage.

Since road accidents in particular DG-HGV accidents are in general rare events, a sufficient large data set needs to be collected in order to obtain reliable statistical values. The occurrence of accidents can in general be described by a Poisson distribution. A good estimation for the upper boundary of the statistical error is then given by the following figure (inverse Chi² distribution).



Simply speaking, the figure describes the relation between the increase of data-set size (number of documented accidents) and the decrease of the statistical error ¹, indicating that the error is

- heavily decreasing between 1 and approximately 10 documented accidents,
- moderately decreasing between approximately 10 and 40 incidents,
- Slightly decreasing for 40 incidents and more

Based on this qualitative observation the following rule of thumb may help the user in the assessment of the data quality:

- Accident rates for 10 or less incidents within the observed time period lead to large statistical errors. Great care needs to be taken when discussing risk evaluations calculated based on such rates. Additional analysis, e.g. sensitivity analysis, should be carried out to reflect the uncertainty of the accident rate.
- Accident rates for approximately 20 or more incidents within the observed time period lead to much smaller statistical errors, which can still be significant but may be small compared to other unknown uncertainties in tunnel risk assessment (behaviour of evacuating persons, fire growth, etc.).
- Accident rates for approximately 50 or more incidents within the observed time period still lead to maximum errors of approximately 25 % (of the observed accident number) but an increased data set size does not significantly decrease the statistical error.

In addition to the absolute number of documented incidents also the quality of the documentation needs to be taken into account.

- Are all material accidents reported or just those with damage to persons?
- Had there been special circumstances influencing the number of accidents for specific time periods during the observation – lane closures, congestions or special speed limits due to construction work, for example.
- Etc.

In general, the evaluation of a specific accident rate for the route under investigation is always highly recommended. In case the available data set is too small to obtain reliable accident rates, the comparison between default accident rates and specific accident rates can still help to reveal accident hotspots, which could be taken into account by an adaption of the most applicable default accident rate.

The accident rate of **heavy-good vehicles** in combination with the conditional probability for the release of dangerous goods leads to the further used scenario frequencies. However, due to a limited data set, the number of accidents with heavy-good vehicles can be too small to allow for a reliable evaluation. In such a case also the overall accident rate, which very often does not significantly differ from the accident rate specifically for heavy-good vehicles, may be used, as in the model, the accident rate is then applied to the HGV traffic only.

¹ This relation between number of documented accidents and the expectation value for the number of accidents, does not depend on the size and traffic of the underlying route. In other words, a short route with low traffic observed over a long period leads to the same statistical quality than a large part of the road network with heavy traffic observed for a short period.

DG-HGV transport correction factor:

This factor, which can be set based on default values or as a custom input, accounts for the reduced accident frequency of dangerous goods vehicles in comparison to ordinary heavy-goods vehicles. The reduction is usually connected to the increased awareness of the driver for the potentially dangers associated with the carried load, better equipment of DG-HGV or specific driver training. As the specific correction factor for the route under investigation is most likely unknown, the default value from France, which was obtained from a statistical evaluation of incidents, may be used and eventually adapted, if specific measures – like special driver training – are in place.

Population densities:

As explained in the UserGuide, for the open sections, calculations may be performed with 2 different approaches:

- a simplifying one where local population densities are considered as uniform along parts of the route (1D),
- a 2D description of the populations (grids).

Population densities along the routes are of course an important parameter in the risk assessments performed by the QRAM. For this reason, no default values are proposed by the QRAM, either in the 1D or 2D approach of the model. In both cases, a survey and collection of local population data (residents, employees, businesses, etc.) should be conducted in order to determine for each period of time:

- the population densities for each route section (1D approach),
- the numbers of people located in the previously determined population grids (see 6.2.3.1 Entering 2D population densities)

A separate population density must be determined for each of the defined time periods, i.e. quiet and normal (and peak if selected), see discussion on global traffic above.

Advice for using scenarios 11 and 12 for alternative toxic substances

Only an expert user should modify the toxicity parameters or probit functions in the expert user interface. For the attribution of toxic substances to the appropriate scenario, refer to the hazard code or label/scenario correspondence matrix proposed above. Nevertheless, it is important to remember that acrolein, the dangerous substance considered as reference for scenarios 11 and 12, is a particularly toxic product, non-representative of the majority of toxic products of Class 6. In terms of pure toxicity, acrolein is even more toxic than chlorine, which is already particularly toxic. When a counting reveals the presence of toxic liquids in the DG traffic, it should be ensured that the products transported have toxicities equivalent to those of acrolein (according to acute toxicity sheets). If not, it should be borne in mind that the risk assessment for these two scenarios is very high in terms of severity (over-estimation).

Advice for Empty vehicles and unidentified dangerous goods

Empty vehicles

Special attention must be paid to empty but uncleaned transports which still appear in the DG statistics but usually have a much lower potential for the associated scenario consequences. This can be taken into account either in reducing the total number of DG-HGV traffic (by the share of empty or not fully loaded lorries) or by only applying the share of fully loaded transports in the DG composition definition and keeping the total DG-HGV traffic. In the latter case the share of empty or not fully loaded transports will still be calculated as “Remaining part” corresponding to “Others (DG potentially leading to at least 20 MW fire)”, whereas with the first approach empty or not fully loaded transports will be neglected completely.

In some cases, empty but uncleaned dangerous goods vessels pose a specific threat that needs to be taken into account. One very specific issue is the consideration of empty but uncleaned gasoline tankers because of the remaining explosive air/gasoline vapour mixture in the almost empty tank. As a conservative estimation, the threat of gasoline vapour explosions can be addressed by increasing the share of scenario 3 – BLEVE of LPG in cylinders.

For a standard gasoline tanker, the maximum mass of available combustible gasoline vapour is related to the volume of the vessel (30'000 l), the upper threshold of the explosive range (7.6 %) and the density of gasoline vapour (4.8 kg/m³), and results to be roughly 11 kg. The combustion enthalpies of gasoline (47.3 MJ/kg) and propane (50.3 MJ/kg) are very comparable. Therefore, adding the transport share of empty gasoline tankers to the transport share of scenario 3 – BLEVE of LPG in cylinders – is a conservative, though possible method to estimate an upper boundary for the effect of empty but uncleaned gasoline tankers. The rate of overestimation is about 4.5 (50 kg to 11 kg).

Unidentified dangerous goods

Route-specific information about the transported dangerous goods may also contain a number of transports with unidentified dangerous goods. Often DG-transports are not identified correctly either because hindering effects during the traffic count or because of incorrect or missing placarding. In such cases only the DG-transport but not the specific type of DG is documented. Usually, the number of unidentified DG transports represent a minority compared to those with recorded UN numbers or hazard identification numbers. In such a case, the distribution of unidentified dangerous goods – due to unreadable placarding for example – should follow the same distribution as for the identified dangerous goods. **Therefore, the number of unidentified dangerous goods should be added to the scenarios, aliquot to the DG-distribution obtained by the identified dangerous goods on the route.**

If, however, the number of unidentified dangerous goods is significant compared to the identified ones, severe issues during the traffic count may have occurred (e.g. low visibility due to bad weather) and the traffic count may need to be repeated.

Advice how to distinguish categories E and D (without using the DGQRAM model) for countries that don't use scenario 1 and 2

The distinction between categories E and D can be made by a qualitative approach based on criteria such as :

- the risk of traffic accidents not involving the transported dangerous goods
- the vulnerability of a route to accidents involving the dangerous goods being transported (natural site threatened by accidental pollution, presence of sensitive structures (bridges, tunnels, historic buildings, industrial sites, etc.) likely to suffer serious damage
- nuisances caused by HGVs on a route (noise, road congestion, etc.)
- socio-economic constraints (length of diversions or additional travel time on the alternative route to the tunnel)
- constraints on the viability, particularly in winter, of a route and their exposure to natural hazards likely to affect them (flooding, avalanches, rock falls, landslides, forest fires, etc.) and thus make it difficult to manage an accident involving a DG or even be the cause of one
- the distance from the emergency services.

ANNEX 10

DATA INPUT INTERFACE FOR CALCULATION OF TUNNEL RISK

1. Introduction

1.1 *Monitoring of developments*

The QRAM data input interface is a tool designed to simplify the input of data required for the calculation of risk for tunnels, using the QRAM.

Changes to the intrinsic risk calculation data input interface are tracked by a version number consisting of the version number of the QRAM with which the data input interface is compatible.

This guide relates to version 4.10 of the data input interface, compatible with version 4.10 of the QRAM.

1.2 *Acronyms*

DG	Dangerous Goods
HGV	Heavy Goods Vehicle
IR	Intrinsic Risk = risk for a tunnel
QRA	Quantitative Risk Assessment
TDG	Transportation of Dangerous Goods

2. Using the data input interface

2.1 Introduction

The data input interface refers only to the data needed to calculate the intrinsic risk for a given tunnel.

The data input interface has been developed so that the input data can be entered in the form that is closest to the one usually used in new construction design or by road tunnel operators, and not in the form required for the QRAM, which is sometimes unusual for users, which use the QRA data input interface for the first time. Knowledgeable users of the QRAM will therefore need to be aware of the conventions adopted by the data input interface.

The main difference is in the marking conventions, which relate to the direction of travel of the tube under consideration. The units adopted are those commonly used rather than those used in the QRAM. Some common data (e.g. average daily traffic), which are not directly required as input for the IR calculation, are reconstructed from the input data and displayed by the data input interface to allow the user to check the consistency of the input.

One other important improvement consists in simplifying the definition of QRA tunnel sections: with the data input interface, it consists in choosing the type of tunnel, and the data input interface carries out all the work of tunnel section definition according to the QRAM.

Data entry and control are facilitated by an interactive formatting. A colour code, explained on the starting page, indicates to the user the nature of the fields displayed on the screen.

Calculation of Intrinsic Risk - Data input interface

version 4.10-13 scenarios

The present input interface is an additional tool to the DG-QRAM software that helps to generate a DG-QRAM calculation (input and output files) for a tunnel, in a simplified way, instead of using the full DG-QRAM model and the different dialog boxes.

For some DG-QRAM parameters, default values are determined by the use of this data input interface. These parameters, as well as all parameters defined by the user by the help of this input interface (entrance data), can as usually be modified in the DG-QRAM input file, which is generated as an output of the present tool

Warning :

Reliable knowledge of the overall traffic, in particular the dangerous goods traffic, as well as the tunnel safety design is essential for the intrinsic risk calculation. In absence of this data, calculated risk values might not be representative.

The following color code is used:

Automatically calculated cell	
Input required from the user	Value to be entered by the user
Inappropriate user supplied value, to be deleted	
Button to click to perform the indicated action	

The values must be entered exclusively in cells where the text appears in black on a turquoise background.

Figure 1 : Introduction sheet

The fields on a turquoise background await input from the user. This may be a choice to be made from a drop-down list, or a numerical value to be entered. The value entered (or modified) by the user normally appears in black.

Values that appear in green are protected. The user cannot change them directly in the data input interface. They appear on a turquoise background if they inform the user about a data to be entered in the neighbouring cell, on a yellow background if it is general information (which can change automatically according to the context), or on a grey background for action buttons.

Values or text appearing in red draw the user's attention to an error or inconsistency that needs to be corrected. This may be a warning message (which disappears when valid data is entered) or it may be values entered by the user which are clearly incorrect and should be corrected or deleted as appropriate.

The content of cells that are not intended to be entered or changed by the user is protected.

In order to preserve the automatic cell formatting rules, **the user should refrain from copying and pasting**. The handle function for copying cells by drag and drop is deliberately deactivated when the data input interface is opened (and reactivated when it is closed so as not to affect the use of other applications) to prevent this risk. Clickable buttons allow the recopying of an identical set of data (see below) and therefore exempt the user from having to copy/paste.

These conventions are the same than in QRAM.

The user is guided through the data entry process in 10 steps, corresponding to 10 worksheets numbered 1 to 10, as detailed below. The user must manually pass to the next worksheet once he has finished to fill in a sheet.

It is possible at any time to go back, to change the sheet, to interrupt the input by saving the file, and then to resume it later, without losing any data.

As it is the case for the data file created with QRAM using the common dialogue boxes, parameters of the data file generated by the data input interface can be modified in analogy. It is the case for all the data that are entered in the interface by the user, and also for some parameters that are directly determined by the interface:

- **default population densities according to tunnel surrounding areas (rural, semi-rural, peri-urban, urban)**
- **DG distribution through the proposed assignment between DG danger codes and the associated DG scenarios of QRAM**
- **traffic interruption time through the level of surveillance and installed (safety) equipment of the tunnel**
- **alert level through the same auxiliary fields as for the interruption time (above)**

All the points are detailed in the next chapters.

2.2 General conventions

The data input interface allows the calculation of the intrinsic risk for 3 common road tunnel geometries:

- bidirectional single tube;
- unidirectional twin tube;
- unidirectional single tube.

The QRAM is not able to handle structures with more complex geometries (e.g. an underground interchange, or a tunnel with covered entry or exit ramps). In such a situation, a possible simplification is to consider only the main tube and to neglect the existence of the ramps. The data input interface therefore has the same limitations as the QRAM.

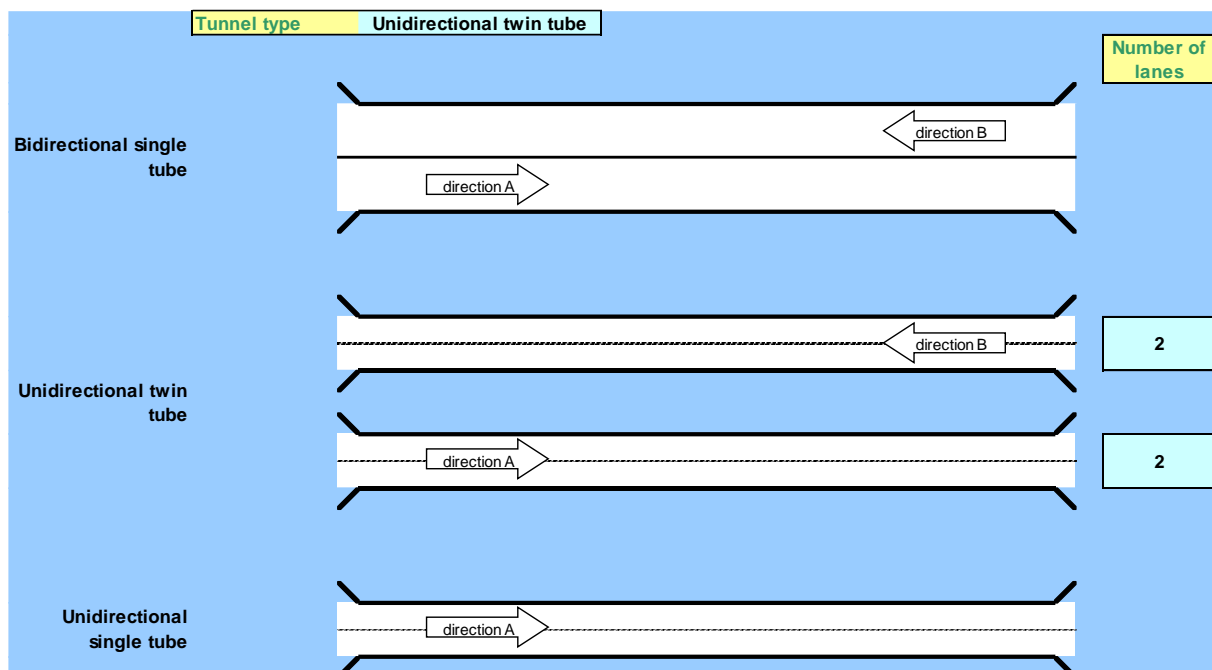


Figure 2 : Choice of tunnel type in the data input interface

Figure 2 illustrates the selection of a unidirectional twin tube tunnel. The user selects this type from the drop-down list and enters the number of lanes in each tube in the cells that appear opposite the illustration.

One direction of traffic is arbitrarily designated "direction A". The other direction is designated "direction B". Most of the data is requested separately for each direction, except in the case of the unidirectional single tube (where the data for direction B, in the open air, is not requested). Subsequently, the data input interface systematically specifies to the user whether the data requested relates to either direction A, direction B or both directions together, noted as "direction A+B".

Once a choice has been done, all the other data to enter are structured according to the type of tunnel.

2.3 Situation Environment

The following sheet allows to enter the number of time periods (1 to 3) and the associated ratio. The ratio of the first period, called normal, is automatically calculated according to the ratio of the other periods, knowing that the sum of the ratios is necessarily 1.

For example, the periods can correspond to:

- normal: daytime;
- quiet: nighttime;
- peak: rush hours.

The associated ratio then depends on the number of daily hours in each period (number of hours in the period / 24).

In some touristic regions, peak or off-peak periods can be distinguished depending on the season. As it is not possible to define 4 periods (day in low season, night in low season, day in high season, night in high season), it is then recommended to consider one single night period which is identical, on average, whatever the season.

Moreover, it should be kept in mind that the calculation of IR only concerns the periods when TDG are allowed to circulate, which often excludes certain days, depending on local regulations.

Some of the input parameters are subject to regular periodical evolutions (e.g. daily / season) such as traffic numbers or occupancies. As in the DG-QRAM, these variations can be taken into consideration by defining the respective values for up to three different periods (Normal, Quiet and Peak)

We can cite for example the traffics and the populations which can vary according to the periods.
The corresponding time periods (3 periods maximum) will be distinguished between normal period, calm period and peak period.

Number of time periods	3		
	Normal period	Quiet period	Peak period
Period time ratio	0.500	0.417	0.083
Environment	peri-urban	peri-urban	peri-urban
Population density at tunnel heads (inhab / km²)	1000	1000	1000

By choosing between the 4 environments (peri-)urban and (peri-)rural, the user helps choosing the predefined population density at the tunnel portals, and the type of environment of urban / rural in the sense of the QRA model.

Influence on the calculated risk levels

The "urban/rural" parameter influences the number of victims of the scenarios, counted among the local population. This influence is however weak because most of the risk is generally born by the road users when the route is mainly tunnel.

Figure 3 : Situation – Environment sheet

On the same sheet, the user also enters the type of environment (urban, peri-urban, semi-rural, rural). The population density applied to the portals is defined according to this choice, and also the parameter rural/urban of the QRAM, which influences the number of victims of the scenario.

By default, the values corresponding to the four types of environment are the following:

Environment	Population density in inhabitants/km². (default values)
rural	100
semi-rural	500
peri-urban	1000
urban	5000

It is also possible to define a different type of environment for different time periods.

If other population densities are required, the parameter can be changed in the generated data file.

2.4 Global traffic

All-vehicle traffic should be provided for each direction of traffic, including in the case of a bi-directional tunnel. If no separate data are available for each direction, a possible approximation is to consider that the traffic is balanced in each direction.

To simplify the input, a button is provided to automatically copy the data from direction A to direction B. The user can then make the necessary changes.

For information and verification purposes, the data input interface calculates the average daily traffic for each type of vehicle (total traffic, HGV, bus), by direction and globally.

The vehicle occupancy rate is a configurable value and it is possible to determine:

- The average number of persons in a car;
- The average number of persons in a HGV;
- The average number of persons in a bus;

The values can be modified directly in the sheet 4_Global_traffic (boxes N11, N12 and N13).

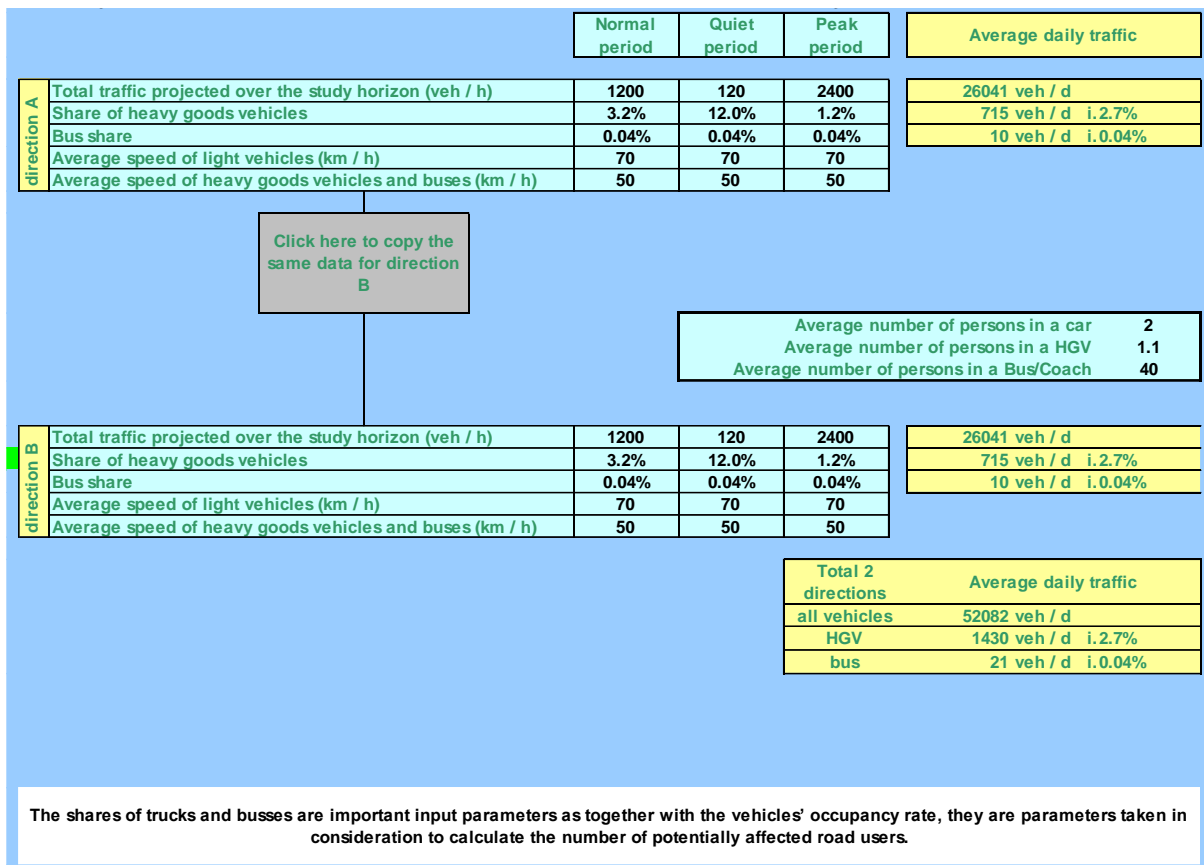





Figure 4 : Global traffic in data input interface

The user has the possibility to define a different volume and composition of TDG traffic per direction, as shown in Figure 5. If the User estimates the Composition of DG traffic is very different in both directions and fills in cell H11 accordingly, then the input table has only one column "direction A+B" instead of the two columns "direction A" and "direction B".

The data input interface asks for the **number of vehicles carrying each of the hazard codes** to automatically deduce the ratio associated with each scenario, accordingly to the correspondence table above.

For some hazard codes, the type of packaging is important. Two lines are then provided for input, "cylinder" to characterise a vehicle as carrying a frame of cylinders, and "bulk/unknown" otherwise.

Vehicles with a hazard code not included in the proposed list, as well as vehicles with a blank orange label without any of the  ,  or  sign, should not be considered here as they do not have a QRA scenario associated with them.

2.6 Exploitation

The sheet "6_Exploitation" is used to enter the level of surveillance and equipment of the tunnel. The data input interface automatically deduces the traffic interruption time and the alert level associated.

direction A	Level of surveillance / human supervision	Human surveillance 24 hours a day		
	Video surveillance	VRAI		
	Automatic Incident Detection	VRAI		
	Use of lane-closure signs and/or lane indicators in tunnel	FAUX		
	Closing device (traffic light or barrier)	VRAI		
	Overlay of radio messages on the FM band	VRAI		
	Variable message sign in tunnel	FAUX		
	Tunnel fire detection	VRAI		
Click here to copy the same data for direction B				
direction B	Level of surveillance / human supervision	Human daytime surveillance		
	Video surveillance	VRAI		
	Automatic Incident Detection	VRAI		
	Use of lane-closure signs and/or lane indicators in tunnel	FAUX		
	Closing device (traffic light or barrier)	VRAI		
	Overlay of radio messages on the FM band	VRAI		
	Variable message sign in tunnel	FAUX		
	Tunnel fire detection	VRAI		
		Normal period	Quiet period	Peak period
direction A	Traffic interruption time	120	120	120
direction B	Traffic interruption time	120	240	120
direction A	Alert level	2	2	2
direction B	Alert level	2	2	2

Figure 6 : Exploitation parameters

The fields to be filled in are:

- Level of surveillance / human supervision
- Video surveillance
- Automatic Incident Detection
- Use of lane-closure signs and/or lane indicators in tunnel
- Closing device (traffic light or barrier)
- Overlay of radio messages on the FM band
- Variable message sign in tunnel
- Tunnel fire detection

The monitoring and equipment levels may be different for each direction. In most cases, they are the same and the click button will automatically copy the data for direction B (when it is a twin-tube tunnel).

The purpose of the monitoring type information is to determine the time between the beginning of the event and the stopping of the traffic at the tunnel entrance, as well as the delay for the activation of the ventilation system in case of fire. This delay also depends on the presence of other operating systems (see diagram below).

The default values of the delays considered (one value for the normal and peak period, one value for the off-peak period, in seconds) are determined according to the diagram below:

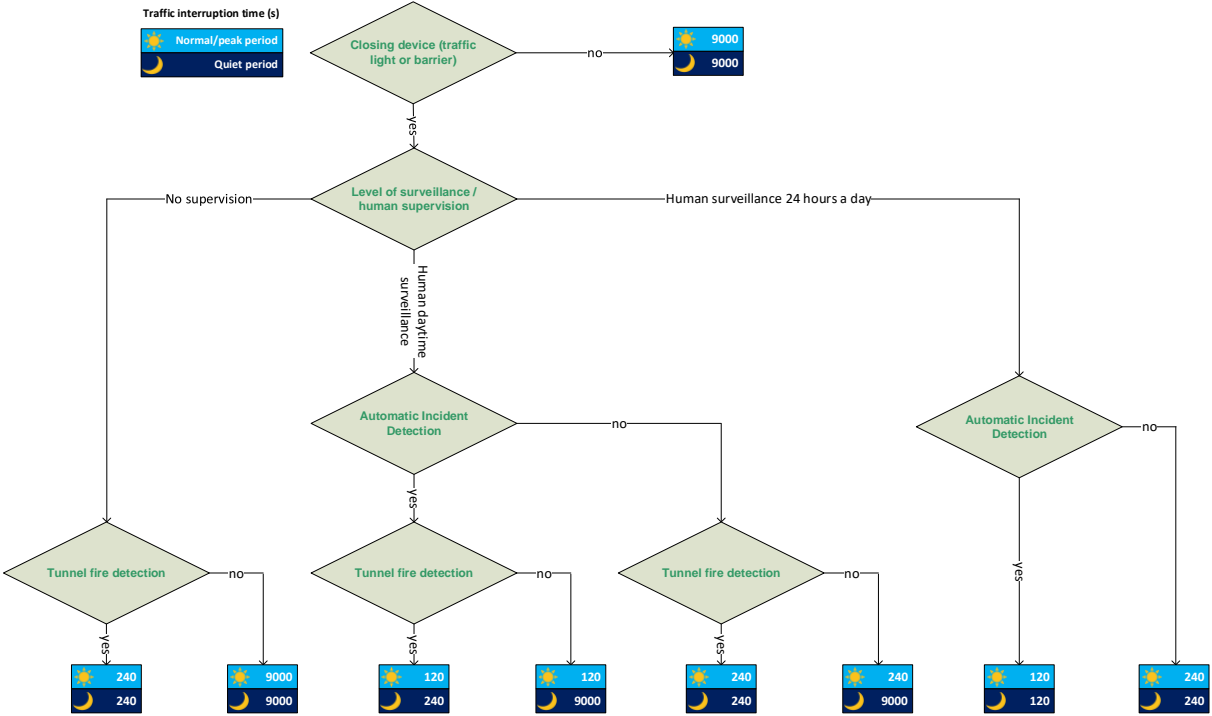


Figure 7 : Traffic interruption time diagram

It should be noted that the type of ventilation system specified by the user in the data input interface is consequently ignored by the model if the tunnel is not monitored and if there is no fire detection system either (in this case, the ventilation fire regime cannot be activated in time to be able to intervene effectively; the conditions then correspond to natural ventilation).

The alert level varies on an integer scale from 0 to 3 depending on the equipment level N in the tunnel.

Detecting and warning systems	If exists
Video surveillance	1
Automatic Incident Detection	1
Use of lane-closure signs and/or lane indicators in tunnel	1
Closing device (traffic light or barrier)	1
Overlay of radio messages on the FM band	1
Variable message sign in tunnel	1
Sum	N

N	Alert level
0	0
1 to 2	1
3 to 4	2
>4	3

The alert level is calculated with these criteria in the "6_Exploitation" sheet of the data input interface.

2.7 Characteristics of tunnel

Sheet "7_Characteristics_of_tunnel" is used to describe the geometric characteristics of the tube(s).

A first table appears for the first tube. For a twin-tube tunnel, this table is reproduced and must also be filled in for direction B. Otherwise, it is automatically hidden.

direction A	Tube length (m)	1200			
	Open cross-sectional area (m ²)	60			
	Effective height (m)	6.0			
	Camber	2.0%			
	Drainage system	continuous slot gutter			
	Slot width (cm)	6.0			
	Number of emergency exits	2			
direction B	Number of segments with constant slope	3			
	Longitudinal profile	Segment No.	1	2	3
		Length of segments listed in order of travel direction (m)	400	600	200
		Slope of segments [+ if rising in the direction of travel, - if descending in the direction of travel] (%)	1.0%	1.5%	-2.0%
		Tube length (m)	1200		
Open cross-sectional area (m ²)	60				
Effective height (m)	6.0				
Camber	2.0%				
Drainage system	drains				
Average pitch between outlets (m)	50				
Section of outlets (m ²)	0.08				
Number of emergency exits	2				
direction B	Number of segments with constant slope	3			
	Longitudinal profile	Segment No.	1	2	3
		Length of segments listed in order of travel direction (m)	200	600	400
		Slope of segments [+ if rising in the direction of travel, - if descending in the direction of travel] (%)	2.0%	-1.5%	-1.0%
		Tube length (m)	1200		
Open cross-sectional area (m ²)	60				
Effective height (m)	6.0				
Camber	2.0%				
Drainage system	drains				
Average pitch between outlets (m)	50				
Section of outlets (m ²)	0.08				
Number of emergency exits	2				

Note: The longitudinal profile must be described in the traffic direction A

Note: The longitudinal profile must be described in the traffic direction B

Click here to copy the same data for direction B in case of symmetric tunnel tubes

Figure 8 : Tunnel characteristics

For each tube, the data to be filled in is:

- The open cross-sectional area (in m²) and the effective height (in m). This is the total surface area of the traffic space (and not just the road gauge) as it appears on a typical cross-section. The same cross-sectional area must be applied throughout the tube. If a structure has large variations in cross-section, the average value representative of the largest linear area may be used, and/or the calculations may be carried out according to the extreme values as part of the sensitivity study to obtain a minimal and maximal value for the IR.
- The camber (transverse tilt) of the roadway (in %). If the camber varies in certain areas, the average value representative of the largest linear distance may be used, and/or the calculations may be carried out according to the extreme values of the sensitivity study to obtain a minimal and maximal value for the IR. The camber is entered as an absolute value (necessarily ensuring flow towards the gutter).
- The drainage system can be of two types:
 - continuous slot gutter, for which it is simply necessary to enter the slot width;
 - with regularly distributed drains: the user must then enter the average pitch between outlets (in m) and their sections (in m²).

There are intermediate systems that the QRAM cannot consider, for example when the drains discharge into a collector via a fire trap, or continuous slot gutters but which do not discharge into a collector via fire traps. In such a situation, a minimal and maximal value for the IR is obtained by making two calculations with either system.

- The number of emergency exits. This indicates the number of passages through which users will be able to escape from the tunnel to a safe place, so that the data input interface can determine the average distance between them. Direct connections to the outside, inter-tube connections, access to a safety gallery and shelters should therefore be counted. Portals should not be counted here (as the data input interface assumes that users can evacuate through the portals). Two opposite exits should be counted as one (this is not a count of evacuation passage units). Finally, in bi-directional tunnels, only exits accessible to users of the same direction of travel shall be counted. The following figure illustrates this point by considering a bi-directional tunnel with exits, some of which are arranged in a staggered pattern on each sidewall. The useful number of exits depends on the possibility to cross the road.

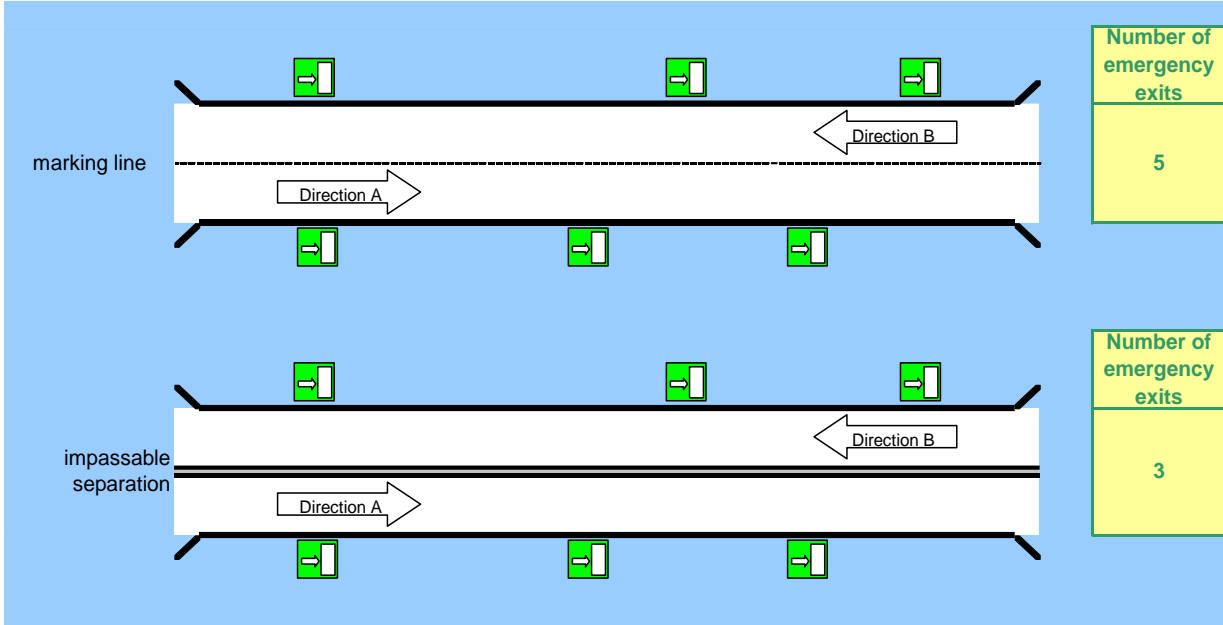


Figure 9 : Illustration of the number of exits to be considered according to their location

- The longitudinal profile is described in segments (1 to 7), **with reference to the direction of travel of each tube**. For a bi-directional tube, the positive direction is arbitrarily assigned to direction A. The slope, expressed in %, is given positively for uphill and negatively for downhill, for the considered direction of traffic.

In the case of a two-tube tunnel, a clickable button allows the values entered for direction B to be copied automatically. During this automatic copy, the order of the segments and the sign of the slope are automatically reversed because the tubes generally have similar longitudinal profiles. The user can then change the values if the segments are not exactly the same in the two tunnel tubes.

2.8 Ventilation

The data input interface simplifies the input of tunnel ventilation data, especially in the case of a unidirectional structure with longitudinal ventilation (with or without massive extraction). The prior use of a one-dimensional calculation code is still necessary if the initial airflow velocity values and their evolution are unknown.

Two states (initial and final) must be described for each tube, as well as the time delay from one state to the other. The initial state describes the conditions prior to the accident and during the first few moments. The final state describes the conditions after the accident, the start of ventilation and the stabilisation of the regime.

For the definition of these states, it is essential to know that the QRAM adopts some simplifications. For fire scenarios (which are particularly sensitive to the airflow conditions), the rise in power of the source term is instantaneous (from 0 to about 300 MW for example for a pool fire) from $t=0$. Therefore, the initial input conditions must be representative of the conditions to which users will be exposed during the first few minutes and consistent with the other models used.

The scenarios are treated for 5 equally distributed accident locations in the tunnel. The performance of the ventilation is therefore investigated for these 5 locations.

Considering these elements, the data to be entered in the data input interface will be for the two initial and final conditions:

- Air flow speed at the inlet,
- the extracted and blown flows along the tunnel.

As for the geometric characteristics, the positive direction is assigned for each tube in reference to the direction of traffic, or to direction A for a bi-directional tunnel. Contrary to the reference adopted by the QRAM, the data input interface therefore considers that the blocks are listed and measured in order in the direction of traffic, and that a positive airflow velocity represents a flow in the direction of traffic (and vice-versa that a negative velocity reflects a flow against the direction of traffic).

The nature of the data to be entered depends on the type of ventilation. The following chapters specify the expected data.

The user of the data input interface does not have to worry about the correspondence between the ventilation blocks and the segments describing the longitudinal profile. The data input interface supports the segmenting of the tunnel as required by the QRAM in a way that is transparent to the user¹.

¹ As a reminder, the QRAM, initially limited to 15 segments per tube, has been increased to 35 segments to offer more flexibility in cutting.

The tool generates a sketch of the ventilation system corresponding to the data entered :

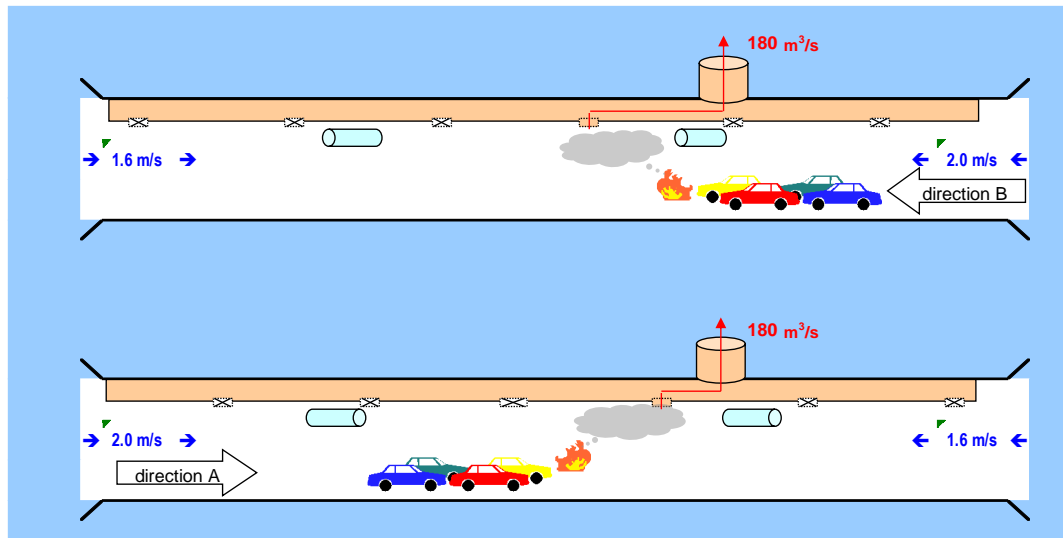


Figure 10 : Schematic display of the ventilation pattern according to data input

2.8.1 Natural and pure longitudinal ventilation system (without massive extraction)

The sheet "8_Ventilation" in the data input interface appears as follows when the user selects a type of natural or pure longitudinal ventilation.

The only data to be filled in are:

- the air flow speed at the inlet at $t=0$ (here resulting essentially from the piston effect of vehicles in unidirectional traffic);
- the final air flow speed at the inlet, which may be different depending on the location of the fire. The data input interface queries the user on the smoke clearing speed obtained for 5 determined locations, equally distributed in the tunnel (in this case at PM200, 400, 600, 800 and 1000 in the example presented where the tunnel length is 1200 m);
- For pure longitudinal ventilation: the duration of the transitional period, i.e. the delay between the initial and final conditions (the value is restricted between 0.5 and 10 min in the data input interface).

Type of ventilation		Natural	Update the ventilation diagram	
direction A	initial conditions	Description of the initial aeruaic conditions		Air flow speed at the inlet for direction A (in m / s)
				3.5
	Duration of the transitional period		min	Warning: The speed must be positive for an air flow in direction A, negative in direction B
final conditions	Description of the aeruaic conditions for the following fire locations, listed in order in direction A of circulation (m)		Air flow speed at the inlet for direction A (in m / s)	
	PM 200		3.5	
	PM 400		2.6	
	PM 600		1.4	
	PM 800		1.0	
	PM 1000		-1.5	

Figure 11 : Input form for natural ventilation

direction A	Type of ventilation	Pure longitudinal	Update the ventilation diagram	
	initial conditions	Description of the initial aeraulic conditions		Air flow speed at the inlet for direction A (in m / s)
				3.5
	Duration of the transitional period	2.5 min		Warning: The speed must be positive for an air flow in direction A, negative in direction B
	final conditions	Description of the aeraulic conditions for the following fire locations, listed in order in direction A of circulation (m)		Air flow speed at the inlet for direction A (in m / s)
		PM 200 PM 400 PM 600 PM 800 PM 1000		4.0 4.0 4.0 4.0 4.0

Figure 12 : Input form for pure longitudinal ventilation

A clickable button allows the characteristics of direction A to be copied automatically to direction B in case of identical airflow conditions.

2.8.2 Longitudinal with massive extraction ventilation system

The sheet "8_Ventilation" in the data input interface looks like this when the user selects a type of longitudinal ventilation with mass extraction(s).

direction A	Type of ventilation	Longitudinal with massive extraction	Update the ventilation diagram		
	Number of massive extractions	1			
	abilities	massive extraction #		1	
		Location of massive extractions, listed in the direction of traffic (m)		600	
		Extraction flow (m ³ /s)		340	
	initial conditions	Description of the initial aeraulic conditions		Ventilation regime applied to massive extraction #	Air flow speed at the inlet for direction A (in m / s)
				1	3.5
		Extraction regime (%)		0%	
	Duration of the transitional period	2.5 min		Warning: The speed must be positive for an air flow in direction A, negative in direction B	
	final conditions	Description of the aeraulic conditions for the following fire locations, listed in order in direction A of circulation (m)		Ventilation regime applied to massive extraction #	Air flow speed at the inlet for direction A (in m / s)
	PM 200 PM 400 PM 600 PM 800 PM 1000	1 Extraction regime (%) 100% Extraction regime (%) 100% Extraction regime (%) 100% Extraction regime (%) 0% Extraction regime (%) 0%	4.0 4.0 4.0 4.0 4.0		

Figure 13 : Input form for longitudinal ventilation with mass extraction (only direction A is shown for the example)

The data to be filled in are:

- the number of massive extraction points (from 1 to 11);
- their location (distance measured from the inlet portal)²;
- their extraction flow capacity (in m³/s);
- the initial extraction regime expressed as a percentage of the extraction flow capacity;
- the final extraction regime foreseen by the smoke extraction programme;
- the air flow speed at the inlet at t=0 (here resulting essentially from the piston effect of vehicles in unidirectional traffic);
- the final air flow speed at the inlet, which may be different depending on the location of the fire;
- the duration of the transitional period, i.e. the delay between the initial and final conditions (the value is restricted between 0.5 and 10 min in the data input interface)..

The data input interface checks the validity of some parts of the data entered: the location of the extractions must be within the tunnel (whose length is defined by the sheet "7_Characteristics_of_tunnel ") and they must be listed in ascending order.

A button to be clicked allows the characteristics of direction A to be copied automatically to direction B.

² For the information of advanced users of the QRAM, the data input interface represents a massive extraction by creating a very short block (arbitrarily 10 m) on which the extraction flow is concentrated, and neighbouring blocks without extraction.

2.8.3 Ventilation system with suction

The sheet "8_Ventilation" in the data input interface looks like this when the user selects a type of ventilation with suction.

direction A	Type of ventilation		With suction				Update the ventilation diagram		
	Number of cantons (segments)		4						
	abilities	segment #		1	2	3	4		
		Length of blocks, listed in direction of traffic (m)		500	500	500	500		
		Extraction flow (m ³ /s)		170	170	170	170		
	Blowing flow (m ³ /s)		40	40	40	40			
	initial conditions	Description of the initial aeraulic conditions		Ventilation regime applied to segment #				Air flow speed at the inlet for direction A (in m / s)	
				1	2	3	4		
		Extraction regime (%)		0%	0%	0%	0%	2.5	
	Blowing speed (%)		0%	0%	30%	30%			
Duration of the transitional period		2.0 min				Warning: The speed must be positive for an air flow in direction A, negative in direction B			
final conditions	Description of the aeraulic conditions for the following fire locations, listed in order in direction A of circulation (m)		Ventilation regime applied to segment #				Air flow speed at the inlet for direction A (in m / s)		
			1	2	3	4			
	PM 333	Extraction regime (%)	100%	0%	0%	0%	0.5		
		Blowing speed (%)	30%	30%	30%	30%			
	PM 667	Extraction regime (%)	0%	100%	0%	0%	-1.0		
		Blowing speed (%)	30%	30%	30%	30%			
	PM 1000	Extraction regime (%)	0%	100%	100%	0%	2.0		
	Blowing speed (%)	30%	30%	30%	30%				
PM 1333	Extraction regime (%)	0%	0%	100%	0%	1.5			
	Blowing speed (%)	30%	30%	30%	30%				
PM 1667	Extraction regime (%)	0%	0%	0%	100%	2.5			
	Blowing speed (%)	30%	30%	30%	30%				

Figure 14 : Input form for ventilation with suction (only direction A is shown for the example)

The data to be filled in are:

- the number of segments (from 1 to 11);
- their length (in m);
- their extraction flow capacity (in m³/s);
- their blowing flow capacity (in m³/s);
- the initial extraction regime expressed as a percentage of the extraction flow capacity;
- the initial blowing speed expressed as a percentage of the blowing flow capacity;
- the final extraction regime foreseen by the smoke extraction programme;
- the final blowing speed foreseen by the smoke extraction programme;
- the air flow speed at the inlet at t=0 (here resulting essentially from the piston effect of vehicles in unidirectional traffic);
- the final air flow speed at the inlet, which may be different depending on the location of the fire;
- the duration of the transitional period, i.e. the delay between the initial and final conditions (between 0.5 and 10 min).

The data input interface checks the validity of the data entered: the sum of the lengths of the blocks must be equal to the length of the tunnel defined by the sheet "7_Characteristics_of_tunnel" and these must be listed in ascending order.

A button to be clicked allows the characteristics of direction A to be copied automatically to direction B. When copying automatically, the order of the blocks and the sign of the airflow velocity are automatically reversed. The user can then correct the values if there are differences.

If an airflow control system exists, the data to be entered is of the same nature. Whether the system uses accelerators or specific smoke control programs, possibly controlled by anemometer measurements, it is the result of this system that is translated into the definition of the input airflow velocity. The user must be careful to ensure that the hypothesis of airflow control is realistic in the case of a very powerful fire that exceeds the system's design, and possibly consider the plausible hypothesis that it will fail.

2.8.3.1 Case of a transverse ventilation system with fixed ventilation sections

This is the simplest case, since the description to be provided corresponds to the physical reality of the sections, which remain identical under all circumstances, and only the extraction- and supply volumes (regimes) vary with respect to the accident location.

Figure 14 above illustrates the case of a 2 000 m unidirectional urban tunnel, with 4 ventilation sections of 500 m each. One extraction plant serves the first two ventilation sections and another one the last two ventilation sections.

2.8.3.2 Case of a transverse ventilation system with remote-controlled dampers

This is the most complex case since the description to be provided must consider the actual extraction areas for each of the 5 accident locations.

Type of ventilation		With suction										Update the ventilation diagram	
Number of cantons (segments)		11											
		segment #											
abilities		1	2	3	4	5	6	7	8	9	10	11	
Length of blocks, listed in direction of traffic (m)		50	600	50	600	50	600	50	600	50	600	50	
Extraction flow (m3/s)		0	110	0	110	0	110	0	110	0	110	0	
Blowing flow (m3/s)		7	90	7	90	5	60	5	60	5	60	5	
initial conditions		Ventilation regime applied to segment #											Air flow speed at the inlet for direction A (in m / s)
Description of the initial aerauc conditions		1	2	3	4	5	6	7	8	9	10	11	
Extraction regime (%)		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1.0
Blowing speed (%)		50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	
Duration of the transitional period		2.5 min										Warning: The speed must be positive for an air flow in direction A, negative in direction B	
final conditions		Ventilation regime applied to segment #											Air flow speed at the inlet for direction A (in m / s)
Description of the aerauc conditions for the following fire locations, listed in order in direction A of circulation (m)		1	2	3	4	5	6	7	8	9	10	11	
PM550	Extraction regime (%)	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1.5
	Blowing speed (%)	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	
PM1100	Extraction regime (%)	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	1.0
	Blowing speed (%)	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	
PM1650	Extraction regime (%)	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0.5
	Blowing speed (%)	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	
PM2200	Extraction regime (%)	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0.1
	Blowing speed (%)	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	
PM2750	Extraction regime (%)	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-0.5
	Blowing speed (%)	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	

Figure 15 : Example 1 of input for transverse ventilation system with remote-controlled dampers

Figure 15 above illustrates the case of a 3,300 m tunnel, with 2 ventilation section for fresh air supply of 1,300 and 2,000 m, with a total capacity of 194 m3/s and 200 m3/s, respectively. Smoke is extracted through remotely controlled dampers with a flow rate of 110 m3/s over a 600 m area centred on the fire.

Figure 16 shows a similar example where the length of the tunnel is only 3000 m. The 600 m extraction zones, where the dampers are remotely controlled, partially cover each other for the different accident locations. The user is therefore forced to divide the tunnel into artificial sections without overlap, and to distribute the flows in proportion to the length.

Type of ventilation		With suction										Update the ventilation diagram													
Number of cantons (segments)		11																							
abilities	segment #																								
	Length of blocks, listed in direction of traffic (m)																								
	Extraction flow (m3/s)																								
		200	500	100	400	100	400	100	400	100	500	200													
		0	92	18	73	18	73	18	73	18	92	0													
		30	75	15	60	10	40	10	40	10	50	20													
initial conditions	Description of the initial aeraulic conditions											Ventilation regime applied to segment #													
												1	2	3	4	5	6	7	8	9	10	11	Air flow speed at the inlet for direction A (in m / s)		
	Extraction regime (%)											0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1.0	
Blowing speed (%)											50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	-1.0			
Duration of the transitional period		2.5 min										Warning: The speed must be positive for an air flow in direction A, negative in direction B													
final conditions	Description of the aeraulic conditions for the following fire locations, listed in order in direction A of circulation (m)											Ventilation regime applied to segment #											Air flow speed at the inlet for direction A (in m / s)		
												1	2	3	4	5	6	7	8	9	10	11			
	PM500											0%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1.5
	Blowing speed (%)											30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%		
	PM1000											0%	0%	100%	100%	100%	0%	0%	0%	0%	0%	0%	0%	1.0	
	Blowing speed (%)											30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%		
	PM1500											0%	0%	0%	0%	100%	100%	100%	0%	0%	0%	0%	0%	0.5	
	Blowing speed (%)											30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%		
	PM2000											0%	0%	0%	0%	0%	100%	100%	100%	0%	0%	0%	0%	0.1	
	Blowing speed (%)											30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%		
PM2500											0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	0%	0%	-0.5		
Blowing speed (%)											30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%			

Figure 16 : Example 2 of input for transverse ventilation system with remote-controlled dampers

2.9 Accident Data

The sheet "9_Accident_Data" is used to define the accident rate considered to calculate the IR. This accident rate can be a calculated value or a value defined by the user. It is possible to define a specific accident rate for each direction.

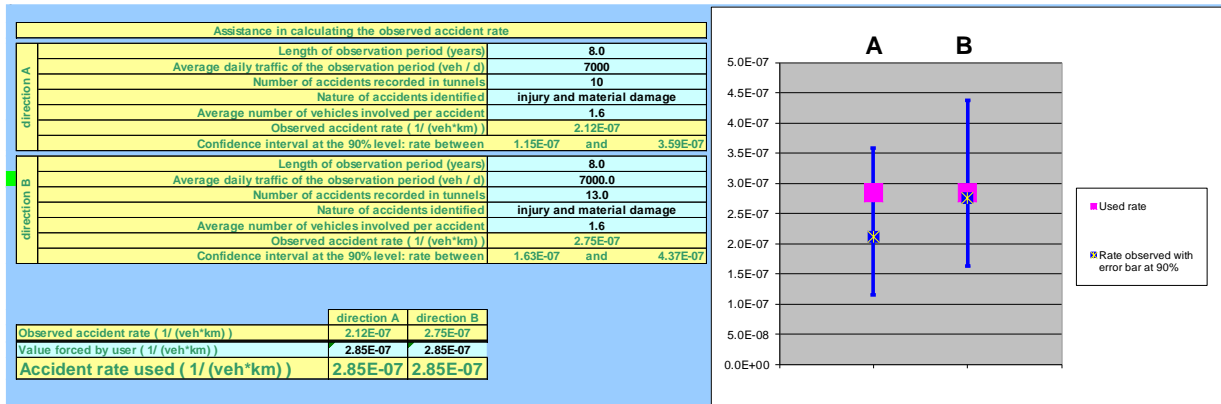


Figure 17 : Accident data in data input interface

When there is relevant feedback on the tunnel concerned, the observed accident rate can be used. The data input interface assists the user in determining this rate. The data to be filled in are:

- Length of observation period (years)
- Average daily traffic of the observation period (veh / d)
- Number of accidents recorded in tunnels³
- Nature of accidents identified (injury and material damage or only injury)
- Average number of vehicles involved per accident

Be aware that the length of the tunnel must have been correctly entered in sheet 7.

Using these elements, the data input interface determines the accident rate for the tunnel (or tube) considered, as well as its 90% confidence interval. There is a statistical 5% chance that the "real" rate is lower than the lower bound, and a 5% chance that it is higher than the upper bound of the interval. The longer the observation period, the higher the number of identified accidents, the narrower the confidence interval will be and thus the more relevant the value of the observed accident rate will be.

At the bottom of the table for entering observed accident data, the rate used for the calculation is displayed. Depending on the user's choice, it is either:

- the observed rate (the user must leave the boxes corresponding to "Value forced by user" empty);
- a rate whose value is forced by the user. If the boxes corresponding to "Value forced by user" are filled in, these are the values that are considered, even if observed accident data are indicated in the tab.

³ Depending on the available data, the user can use either all accidents data (injury and material damage) or only injury accidents data. The formula for calculating the observed accident rate in the sheet "9_Accident_Data" applies a multiplication factor of 6.6 when only injury accidents are reported. This value is derived from the conclusions of the feedback analysis in the QRAM reference manual.

The accident rate applied by the QRAM in the calculations launched by the data input interface corresponds to the HGV accident rate introduced into the data input interface, corrected by a corrective factor, by the application of a final corrective factor reflecting a lower accident rate of TDG than of all HGV.

The corrective factor is 1/2.6.

This correction factor may be edited in the generated data file

2.10 Calculate the IR

On the sheet "10_Calculate the_IR", when all input data has been completed, the user is asked to define the name of the generated data file.

QRA Directory	C:\qram_dg_410\
Name of the generated input file	test.xls
Name of the generated output file (generated by DG-QRAM)	test_11.xls

Start the IR (Intrinsic Risk) calculation

Figure 18 : Start the IR calculation

Clicking on the "Start the IR (Intrinsic Risk) calculation" button starts a procedure to check the consistency of the input data. If an erroneous value is detected, a dialogue box informs the user and positions him on the sheet to be corrected. In this case, no file is created and the user must correct the data before starting the operation again.

If the data input interface succeeds in creating the data file for the QRAM, a message will be displayed after about 30 s to 1 min. This data file is then saved under the designated name in the Savings directory of the QRAM.

The user has the possibility to start the IR calculation (OK) or to abort it (Cancel). If the user aborts the calculation, he/she will be able to run the calculation using the QRAM later.

When the QRAM completes the IR calculation, after a few minutes, the results are available in the result file.

The data file and the result file (with the extension _11) are saved to disk and opened for the user to view.