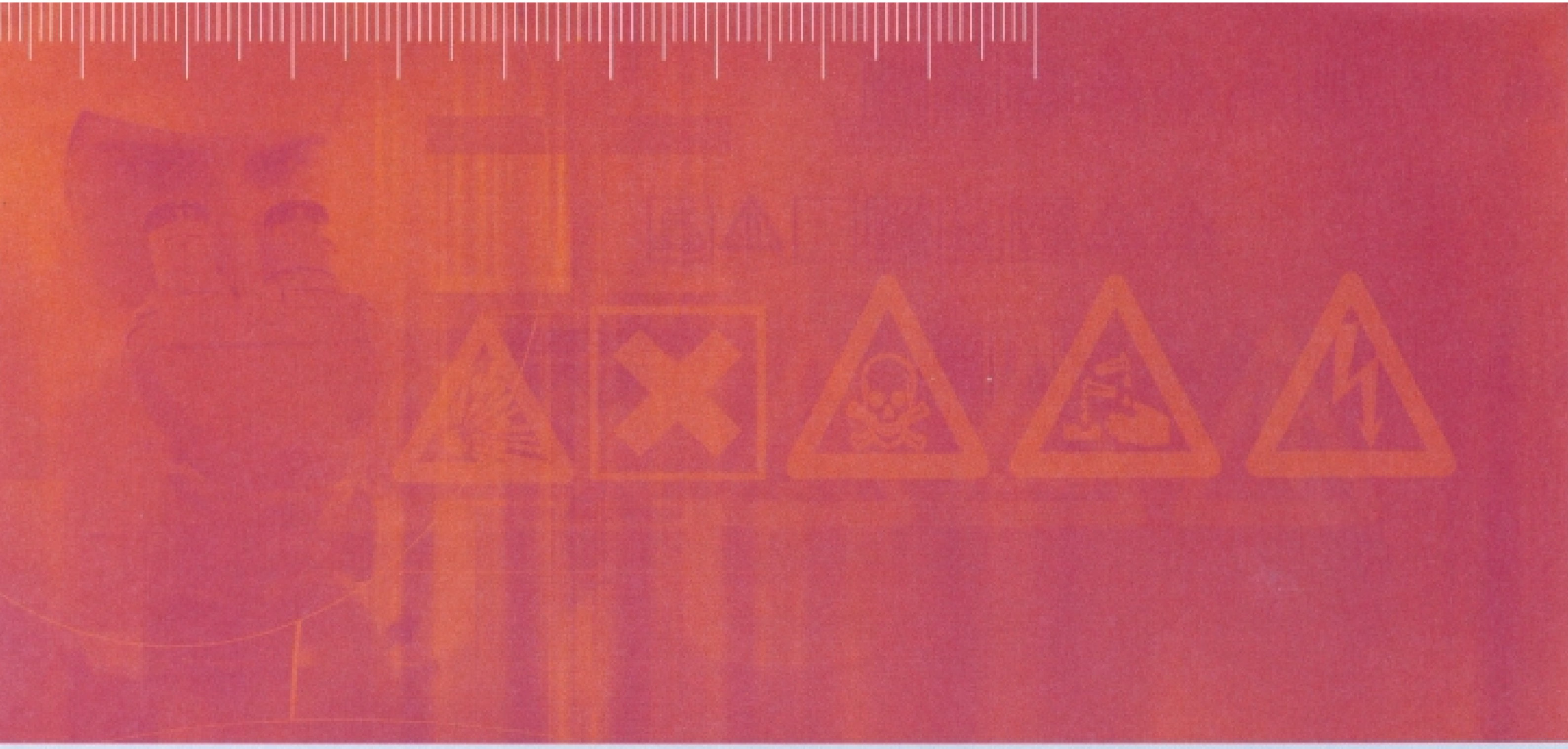

STUDY REPORT 24/07/2018

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METHODOLOGY FOR RISK EVALUATION OF TRANSPORTATION OF DANGEROUS GOODS ALONG A ROUTE

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Methodology for risk evaluation of transportation of dangerous goods along a route

Accident Risks Division

Verneuil-en-Halatte (60)

Contributors: Marine DELAMOTTE, Clément LENOBLE, Thomas MARCON, Valérie DE DIANOUS

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	Written by	Reviewed by	Approved by
Name	Marine DELAMOTTE Valérie DE DIANOUS	Franck PRATS	Sylvain CHAUMETTE
Title	Engineers Risk Quantification and Assessment of Safety Barriers Unit Accidental Risks Division	Senior Technical Adviser	Head of the Integrated Risk Assessment and Management Department Accidental Risks Division
Signature			

CONTENT

1 RISK INDICATORS

The risk indicators, used to perform quantitative risk assessments (QRA), are presented in the following paper. They are of interest to the Transportation of Dangerous Goods and routes comparisons.

This memo reminds the different parameters that should be considered in order to determine these risk indicators.

Two risk indicators may be used:

- **Individual risk**

  Individual risk represents the risk at a given point. It corresponds to an annual likelihood for a person, who is assumed to be present, without protection, of dying due to the occurrence of an accidental phenomenon occurring in an installation or along a route which results in the release of a dangerous substance.

  The individual risk is graphically represented by risk outlines around the installation or route (see Figure 1): the area between two curves corresponds to an annual occurrence probability range.

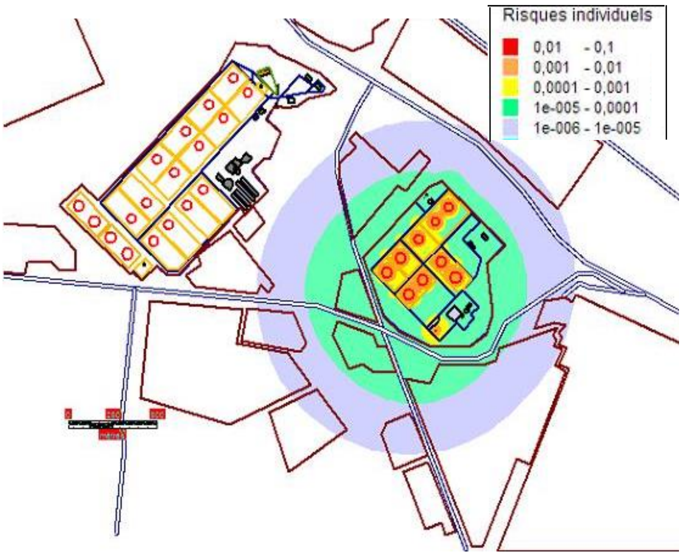

Figure 1: Example of individual risk around an installation

Individual risk is commonly used for land use planning around industrial facilities. It can be useful to ensure the risk acceptability regarding local criteria, such as the nature of vulnerabilities (hospitals, housings, ...) at a given point in the vicinity of an establishment. This indicator is not usually used in the context of transportation of dangerous goods.

- **Societal risk**

  Societal risk corresponds to an annual probability that at least N persons are simultaneously killed because of their presence within the impact area of an accidental phenomena within an installation or along a route which results in the release of a dangerous substance.

  Societal risk can be represented as a frequency / severity curve (F/N curve). The frequency is the frequency of having accidents causing N dead or more. N is the number of dead and F the cumulative frequency of accidents with N or more deaths. Figure 2 illustrates an F/N curve around an installation.

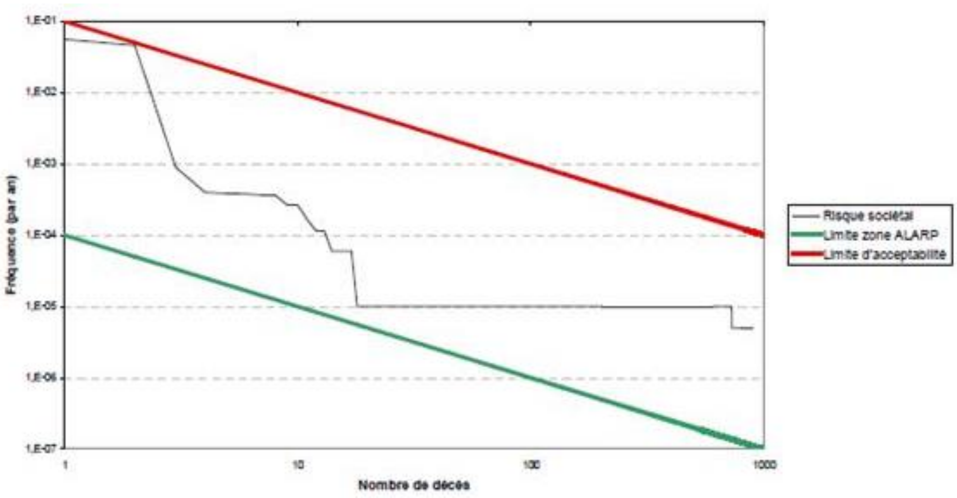

Figure 2: Example of representation of societal risk around a facility

In France[1], this indicator is commonly used for routes comparison in regard with road transport risks. Another use of this indicator is to ensure the acceptability of a section. Worldwide, it is used for ranking facilities (particularly in Great Britain and the Netherlands).

[1] See booklet 3 of the Road Tunnel Safety Records Guide: « Les analyses des risques liés au transport des matières dangereuses – décembre 2005 : http://www.cetu.developpement-durable.gouv.fr/IMG/pdf/Guide_dossier_securite-Fasc_3_cle081e51-1.pdf

2 QUANTITATIVE RISK ASSESSMENT (QRA) PARAMETERS

2.1 PARAMETERS FOR INDIVIDUAL RISK

To assess the probability of lethality at a given point (individual risk), several parameters need to be considered:

- frequency of occurrence of a dangerous phenomenon (meaning prevention barriers failure),
- specific effect probability (thermal, toxic, overpressure...),
- probability of exposure to an effect,
- probability of impact on health (lethal injury),
- presence of the individual.

Frequency of occurrence of the dangerous phenomenon

QRA start with the frequency of occurrence of a dangerous phenomenon.

This parameter depends on:

- loss of containment frequency,
- probability of failure of the safety barriers used to prevent/mitigate the dangerous phenomenon,
- probability of ignition in the case of release of flammable substances: immediate or delayed ignition,
- weather conditions: stability, wind speed, ...
- faction of combustion energy dissipated in the form of thermal energy (e.g. in case of BLEVE),
- etc.

In regard with transportation risk, frequency is expressed in annual frequency per unit of length (linear frequency).

The entire route can be divided into several "elementary steps" of a given length dx. Between two positions x and x + dx, it is assumed that the linear frequency is constant; the frequency on the elementary step is $F_x = f_{linear}.dx$ (see Figure 3).

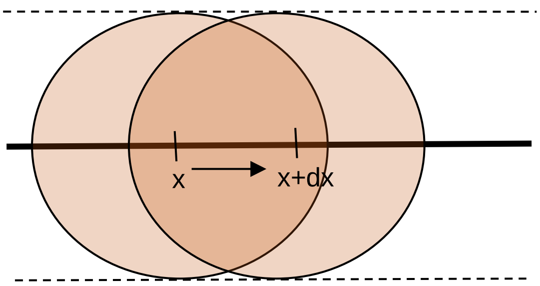

Figure 3

Note: The choice of the "elementary step dx" should be optimized regarding computation times and expected precisions. Especially it may be necessary to choose a step small enough to take into account all specific punctual targets (Figure 4).

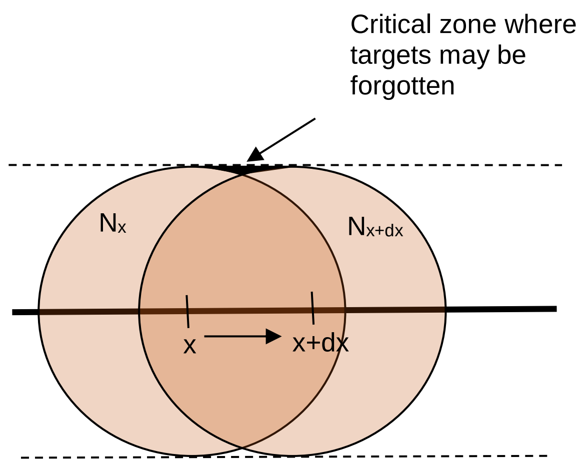

Figure 4

Probability of an effect

For a given dangerous phenomenon, all types of effects need to be considered (thermal, toxic, overpressure...).

Probability of being exposed to the effects

This parameter depends on the effect area, which is linked to:

- wweather conditions,
- environnemental conditions (temperature, solar radiation),
- wind directions,
- probability of immediate/delayed ignition, fraction of combustion energy dissipated as thermal energy, etc.

The probability of exposure for someone located at a point within the bandwidth defined by the effect-area (effect band along the route) equals 1.

If the person is outside this bandwidth, the probability equals 0 (Figure 5).

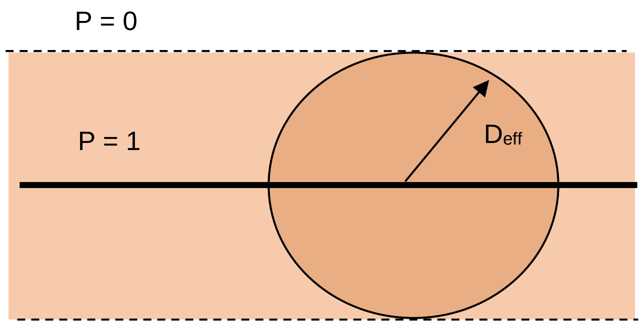

Figure 5

Note: At a given point, the frequency of being impacted by an effect can be evaluated. This assessment is not performed in usual Transportation of Dangerous Goods QRA. It is carried out for transport pipelines risk assessment, in France (for more information, see the Gesip[2] Guide). Thus, it is necessary to define the length L which may impact someone:

- A person located at a point Y in the D_{eff} located within the effects-area (associated for instance to 1% lethality) will be affected by the dangerous phenomenon if the loss of containment occurs between points A and B of the route (Figure 6). The route length L on which the phenomenon occurrence could impact a person located at Y is: $L = 2.\sqrt{(D_{eff}^2 - y^2)}$.
- The impact frequency F_Y at point Y is defined as following:

$$F_Y = f_{lin} \times 2.\sqrt{(D_{eff}^2 - y^2)}$$

With:

- D_{eff} is the distance of effect (radius of the effect circle)
- y is the minimum distance between the point Y and the route.

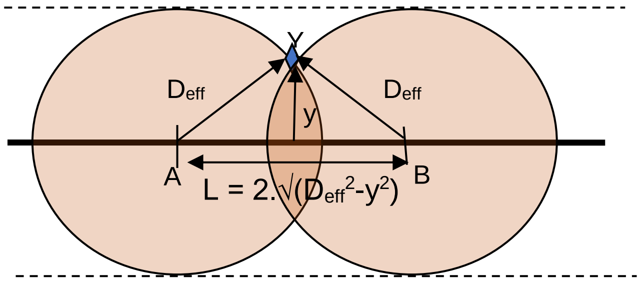

Figure 6

Probability of health effects (lethal injury)

The probability of getting killed by exposure to a dangerous phenomenon can be calculated using probit functions. They are related to the observed dangerous phenomenon, as well as the received dose (depending on the distance from the source).

Lethality percentages are related to the distance from the source. In QRA studies, lethality probabilities are evaluated between the source and a maximum distance corresponding to a lethality threshold (often 1%).

Assuming a dangerous phenomenon occurring at a position x of the route, then the probability, for a person located at the point Y, to be killed is P_x. For a fixed Y, the P_x probability therefore depends on the position of x (Figure 7). P_x will be evaluated for the different positions of x, assuming that Y does not move.

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[2] Methodological Guide for carrying out a safety report on a transport pipeline (liquid or liquefied hydrocarbons, natural or assimilated gas and chemicals) - *Guide professionnel GESIP n°2008-01 – Edition de janvier 2014 - http://www.gesip.com/*

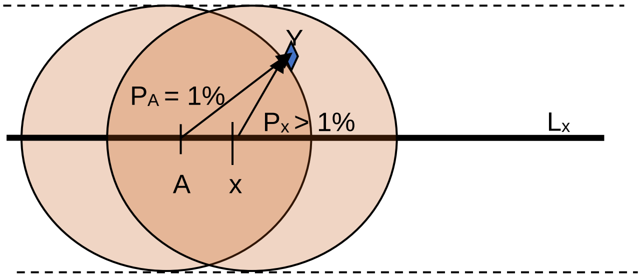

Figure 7

Note: The potential personal protection can be considered (protective equipment, wall, etc.).

Note: For individual risk, lethality probability at a point means lethality frequency of a person located at this point. To map individual risks, iso-risk curves are plotted around the infrastructure considering this probability of lethality at each point.

For societal risk (cf. § 2.2), lethality probability is only one of the parameters of fatalities number assessment.

The frequency, or rather cumulative frequency, is necessary for the representation of the F/N curves (see § 2.4) is therefore not equivalent to the probability of lethality of the individual risk.

Probability of presence of people

For societal risk, the likelihood that people will be present depends on:

- presence distribution (day or night),
- intermittent occupancy (festival, camping site, stadiums, etc.).

Individual risk

The individual risk (IR) at a given point is the sum of the products, for each dangerous phenomenon, of the frequency of occurrence of the dangerous phenomenon ($F(Scen_{i->n})$) by the probability of an effect (P_{eff}), by the exposure probability ($P_{exposure}$), by the lethality probability ($P_{lethality}$):

$$IR = \sum F(Scen_{i\to n}) * P_{eff} * P_{exposure} * P_{lethality}$$

2.2 PARAMETERS FOR SOCIETAL RISK

Frequency of an accident

The frequency of an accident related to a given dangerous phenomenon and to a given effect is the product of the frequency of occurrence of the dangerous phenomenon by the probability of an effect (P_{eff}).

$$F = F(Scen_{i\to n}) * P_{eff}$$

Severity evaluation

For societal risk, it is necessary to assess the severity of each accident (i.e. fatalities number).

The fatalities number is calculated for each scenario, at each point of the effect area, with the number of exposed persons, the lethality probability and the presence probability if necessary.

$$N = \int_{r=source}^{Deff} n_i * P_{presence} * P_{exposure} * P_{lethality}\ dr$$

The number of exposed people n_i can be calculated as follows:

- In case of homogeneous population density in a zone i: the number of exposed persons n_i is the product of this effects area by the density.
- If the density is not homogeneous, the effect area is divided into homogeneous meshes and the number of exposed persons n_i is calculated for each mesh.
  It is important to count everyone. The impacted persons number cannot be divided by the number of meshes.
- In case of punctual targets, they are counted separately.

The values p_i on the graph (Figure 8) basically represent different lethality percentages (or lethality probability). Then, based on the real number of persons present within the effect-area (n_i), the total number of fatalities can be calculated.

In a simplified QRA, assumptions may be made to consider a uniform lethality percentage between two lethality effects-areas (Figure 8). The average or maximum value of the lethality percentage is then selected in the area under consideration. These lethality percentages are used to calculate the severity of each accident N considering the number of persons n_i present in different areas and the different probability of lethality p_i related to the distances of areas:

$N = p_1 \times n_1 + p_2 \times n_2 + p_3 \times n_3$

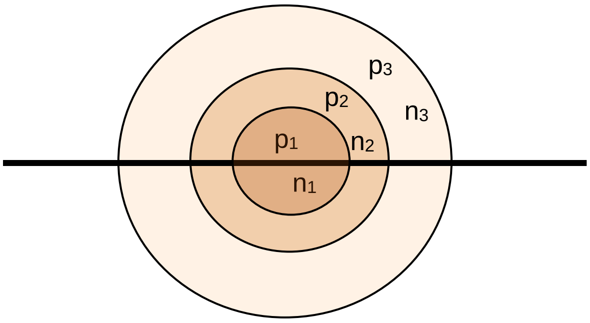

Figure 8

F/N curves

To plot F/N curves corresponding to a route, it is necessary to aggregate all the accidents along the route (occurring at different points x and leading to N_x deaths for each effect). The effects distances (circles for instance) for each dangerous phenomenon have to be moved along the route to cumulate the accidents.

The graph below (Figure 9) represents F/N curves of different scenarios that can occur on the same route.

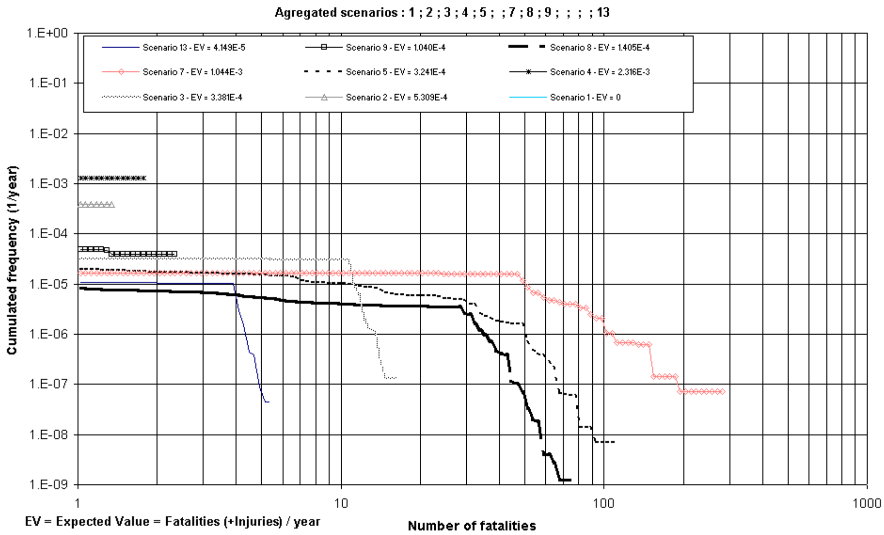

Figure 9

For reminder, an F/N curve is plotted in:

- ranking scenarios in terms of severity level (from N_{max} to N_{min});
- calculating, from the most to the less important severity scenarios, the cumulative frequencies;
- plotting the F/N curve with severity / cumulative frequency.

Thus, for a given number of dead N, the frequency corresponds to the sum of the frequencies of accidents leading to at least N deaths.

The route is evaluated by comparing the F/N curve to the acceptability criteria when these have been defined. For example, acceptability criteria have been defined by the Dutch RIVM and by the British HSE.

2.3 Comparison of routes

Different routes can be compared to each other using F/N curves.

When the F/N curves of the routes are represented on the same graph, if one of the curves is clearly "below" the other without crossing with any other curve, then the corresponding route presents the lowest societal risk.

In any other case, a global indicator may be useful to choose the least risky route, in addition to socio-economic considerations.

Different comparison indicators were found in the literature.

Fatalities Expected Value

The expected value E corresponds to the area under the F/N curve, which is calculated thanks to the following integral:

$$E = \int_{f_i=f_{min}}^{f_{max}} N_i df$$

with:

- E : fatalities expected value of having N dead per year on the studied section
- f_i : cumulative frequency of having N dead
- N_i : number of fatalities.

Comparing fatalities expected values of the F/N curves of different routes makes it possible to determine the least risky: it will be the one with the lowest expected value[3]. However, if the values of expected values are close, no conclusion can be drawn.

It is an indicator that corresponds to an overall vision of societal risk and that does not generally consider the aversion to disasters: an accident making 1 death every year has the same weight as an accident causing 100 deaths every 100 years.

Comparison of areas between the acceptability curve and the F/N curve

Another suggestion is that the comparison of the different areas obtain between the acceptability curve and each of the F/N curves.

Sources:

[1] Cassini, (1998). Road transportation of dangerous goods: quantitative risk assessment and route comparison.

[2] CCPS (1998). Tools for making acute decisions with chemical process safety applications. Cost-benefit analysis p.190.

[3] CETU (2005). Fascicule 3 du guide des dossiers de sécurité des tunnels routiers « Les analyses des risques liés au transport des matières dangereuses » .

[3] Comparison rules are presented in booklet 3 of the road Tunnel safety Record Guide: a ratio greater than 10 is considered significant and makes it possible to make a decision without using other criteria. A ratio of less than 3 is not significant and the use of other criteria is necessary. For ratios between 3 and 10, a sensitivity study is required.

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Institut national de l'environnement industriel et des risques

Parc Technologique Alata
BP 2 - 60550 Verneuil-en-Halatte

Tél. : +33 (0)3 44 55 66 77 - Fax : +33 (0)3 44 55 66 99

E-mail : ineris@ineris.fr - **Internet :** http://www.ineris.fr