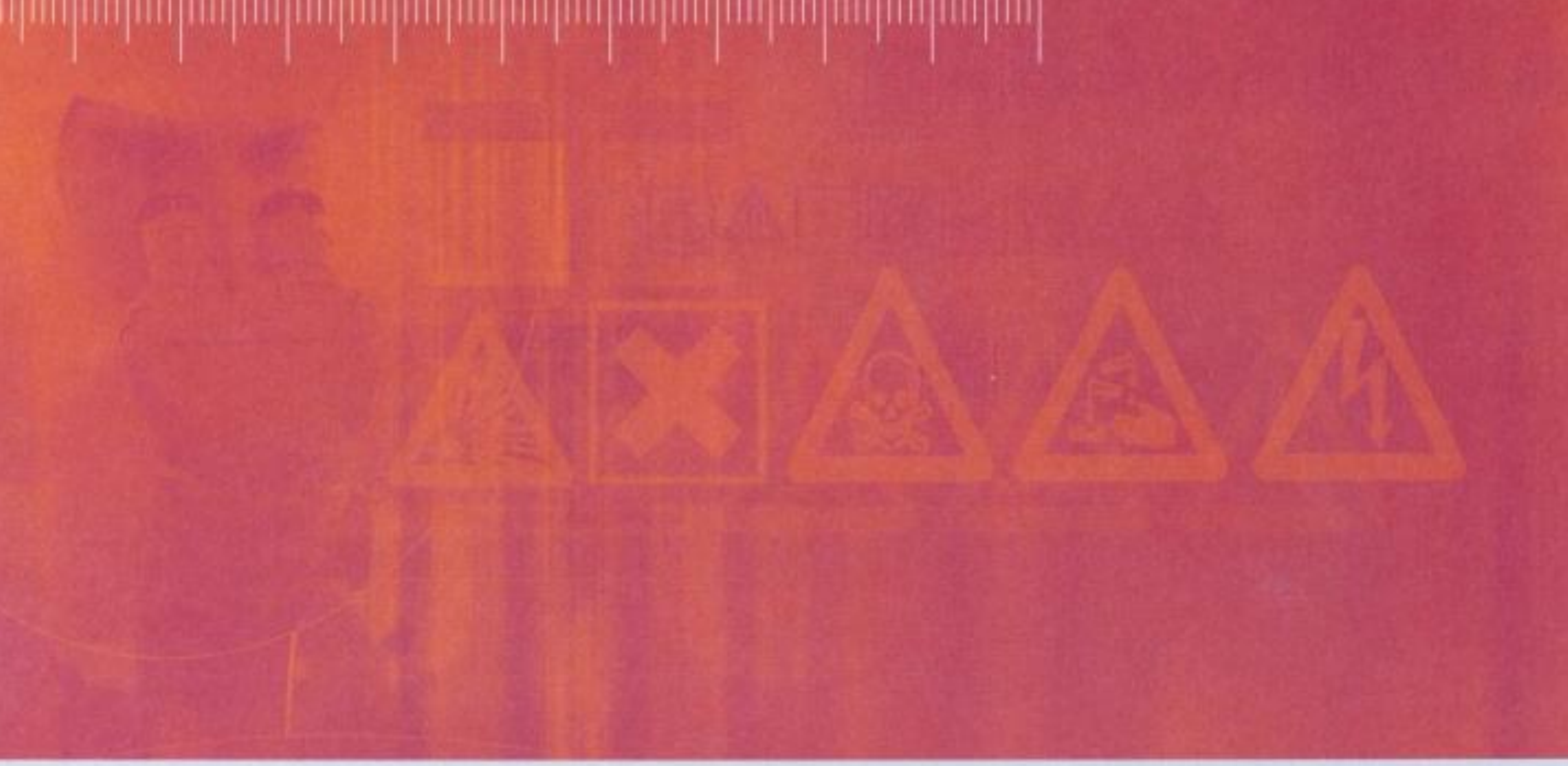

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DRA 71 - Operation A.5

Guide to Implement the ALARP Principle for Installations Classified for the Protection of the Environment (ICPE)

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Accidental Risks Management

Study team: Yann FLAUW, Clément LENOBLE

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GLOSSARY

ACB	Cost-Benefit Analysis
ALARP	As Low As Reasonably Practicable
AM	Major Accident
DREAL	Regional Directorate of Equipment, Development and Housing.
EDD	Safety Report
G	Severity
ICPE	Installation Classified for the Protection of the Environment
IIC	Inspection of Classified Installations
HSL	Health and Safety Laboratory (United Kingdom)
Mi	Measure N° i
MMR	Risk Reduction Measure
NEN	Netherlands Standardization Institute
OECD	Organization for Economic Cooperation and Development
P	Probability (often annual occurrence probability)
PAC	”Porter à Connaissance”: French land use planning document for lower tier Seveso establishments
PPRT	Technological Risk Prevention Plan: French land use planning document for upper tier Seveso establishments
TNO	Nederlandse Organisatie voor Toegepast-Natuurwetenschappelijk Onderzoek (Netherlands Organization for Applied Scientific Research)

1. INTRODUCTION

1.1 CONTEXT

The concept of As Low As Reasonably Practicable (ALARP) first appeared in modern French regulations back in 1977, in the Implementation Decree for the Law of 7/19/76 concerning Installations Classified for the Protection of the Environment (ICPE). This Decree, now repealed, stated in its Article 5 that the safety report (EDD) for an ICPE must "*justify that the project reaches a risk level that is as low as possible under economically-acceptable conditions, taking into account the current knowledge and practices and the vulnerability of the installation's environment*." The ALARP concept was certainly not explicitly mentioned, but the terms "*economically acceptable*" and "*risk as low as possible*" clearly suggested it. What is or is not economically acceptable? How to justify the "*as low as possible*"? The decree did not specify it, and the current regulations are no more explicit.

In the current French regulations, three main texts deal with the acceptability of the risk for the ICPE: the Order of May 10, 2000, the Circular of May 10, 2010 and the Order of September 29, 2005[1].

The Order of May 10, 2000 specifies that "*the approach to controlling [...] accidental risks [...] consists of reducing as much as possible the probability or the intensity of the hazardous effects leading to potential major accidents, given the current knowledge and practices and the vulnerability of the installation's environment*".

The Circular of May 10, 2010 lays down criteria to assess the operators' justification that *"the project reaches, under economically-acceptable conditions, a risk level that is as low as possible, given the current knowledge and practices and the vulnerability of the installation's environment".* These criteria include in particular *"the operator's technical, organizational and financial capacity to maintain a risk level corresponding to the elements contained in the safety report"*.

In these two texts, the ALARP concept is once again not explicitly mentioned, but the issue of reducing the risk under technical, organizational and financial constraints is clearly expressed. However, the risk management approach does not apply to all the risks of major accidents. For Seveso establishments, each case identified in the safety report should be placed on a probability/severity grid, and is assigned a label depending on its position on the grid. For regular licenses (outside the scope of the Seveso

1 Order of 5/10/00 concerning the prevention of major accidents involving hazardous substances or preparations present in certain categories of installations classified for the protection of the environment subject to authorization / Circular of 5/10/10 summarizing the methodological rules applicable to safety reports, to the assessment of the risk reduction approach at the source and to the technological risks prevention plans (PPRT) in the installations classified under the Law of July 30, 2003 / Order of 9/29/05 on the evaluation and consideration of the probability of occurrence, of the kinetics, of the intensity of the effects and of the severity of the consequences of potential accidents in safety reports of classified installations subject to authorization.

Directive), this approach, although not required, is also often applied. The probability and severity scales of this grid are defined in the Order of September 29, 2005. In the grid, three areas of risk are distinguished for Seveso establishments:

- The "NO" boxes, corresponding to a high, a priori, unacceptable risk.
- The "MMR" boxes, for which the approach to risk reduction to as low as possible, under economically-acceptable conditions, must be carried out.
- The "Empty" boxes, corresponding to a low risk area, a priori acceptable in the current state.

The boxes located in the first area ("NO") are in principle rejected.[2] The operator should reduce the risk, by the likelihood of occurrence or the severity of the consequences, in order to move the criticality into an "MMR" or even "Empty" box. Accidents located in empty boxes are considered to be acceptable, as long as the operator can justify that they will remain in these boxes.

Finally, for major accidents located in MMR boxes, the Circular requires an ALARP risk reduction approach, even if the term is not used. However, the practical conditions for the implementation of this approach remain unclear, as shown in the following excerpts:

"Please check that the operator has analyzed all the possible risk reduction measures and implemented those whose ***cost*** *is not* ***disproportionate*** *in relation to the* ***expected benefits****."*

"The "Tolerability" of the risk is the result of a balancing of the advantages and disadvantages (including the risks) related to a situation that will be subject to proper review in order to identify, ***over time*** *and whenever feasible, the means to achieve a risk reduction."*

The Circular thus displays the will to implement the ALARP reduction principle. It even suggests using a cost/benefit analysis to do so. On the other hand, there is no recognized method that would demonstrate that this reduction was properly performed.

INERIS offered in 2011 to the Ministry of Ecology to study the subject, with the aim of proposing a relevant and responsive decision-making support tool. This work mainly relied on two elements: the study of the texts and practices developed in some European countries as well as conversations with the stakeholders, design firms, and the DREAL inspectors.

[2] *It is in practice the Prefect concerned who decides if the risk management approach is acceptable.*

1.2 PRELIMINARY STUDIES

In 2011, INERIS conducted an initial study entitled "European Benchmark relative to the Recommendations for Implementation of the ALARP Principle" [1]. This study consisted of a documentary analysis of the regulatory texts and methodological guides in several countries, in particular the United Kingdom and the Netherlands. Indeed, these countries had the most important concentration of documentation on the ALARP. This study shows that methods exist, in theory, that demonstrate the ALARP risk reduction, often associated with cost-benefit analyses (ACB).

In 2012, INERIS sought meetings with its counterparts in the United Kingdom and the Netherlands to gather information on the practical implementation of the ALARP principle in the approaches to risk reduction. Two days of discussions were thus held:

- in the United Kingdom, meeting with the Health and Safety Laboratory (HSL) on August 31, 2012;
- in the Netherlands, meeting with the Netherlands Organization for Applied Scientific Research (TNO) on November 5, 2012 and with the Netherlands Standardization Institute (NEN) on November 13, 2012.

These discussions helped to understand under what conditions and how the ALARP principle was implemented in both countries. They also resulted in a second report, entitled "Implementation of the ALARP Principle in the United Kingdom and the Netherlands" [2].

This work then was supplemented, in 2013, by meetings with two design firms, Technip and Bureau Veritas, and two DREAL (Midi-Pyrénées and Calais); meetings that helped to clarify the framework for use of the method (paragraph 2), as well as refining the objectives.

1.3 OBJECTIVES

Today, technical-economic studies are sometimes conducted to decide whether a measure should be implemented or not. However, it remains difficult to interpret the results in order to make an informed decision.

The method proposed by INERIS seeks to address this difficulty in this guide. It is a decision-making support tool. The guide is intended for operators of industrial sites and for inspectors of classified installations, to whom it offers a structured approach to justify the risk reduction. It thus guides the decision on whether to implement an additional risk reduction measure or not.

1.4 ORGANIZATION OF THE GUIDE

This guide is organized into four main parts:

- Chapter 2 specifies the framework for the use of the method and its four stages.
- Chapter 3 describes these stages and explains how to analyze and use its results.
- Chapter 4 presents the method applied to two fictitious case studies.
- Chapter 5, finally, explores the prospects for further development of the method.

2. FRAMEWORK FOR THE USE OF THE METHOD

The method fits into the regulatory framework for ICPEs. For the sake of consistency with the Circular of May 10, 2010, the demonstration of ALARP reduction is performed major accident by major accident. The method presented here deals with a single major accident, and must be repeated if the user wants to justify an ALARP reduction over several accidents.

To use this method, major accidents must be quantified by probability and severity. The probability and severity scales used are the scales in the Decree of September 29, 2005: in 5 categories from E to A for the annual probabilities of occurrence of dangerous phenomena and major accidents, and in 5 categories from moderate to disastrous with regard to the severity.

The method proposed here should be understood to be a tool to help in the decision-making concerning the acceptability of the risk. It does not provide strict principles but provides an argumentation in favor of or against the implementation of a new measure. The final decision falls to the manufacturer, the Inspection of Classified Installations (IIC), and even the Prefect, as the case may be.

It was developed and calibrated for the Seveso sites and the most “sensitive” ICPE outside the scope of the Seveso directive. Similarly, the major accidents for which the method was calibrated are the most "critical," i.e., those positioned in boxes E/disastrous or, more generally, the MMR rank 2 boxes on the MMR grid. The method that we propose can however be used, in theory, for any ICPE and for any major accident. On the other hand, the results will perhaps be less relevant (see Chapter 5).

In practice, this method responds to the requests of:

- operators wishing to conduct a "clean" demonstration of an ALARP reduction;
- inspectors of classified installations wishing to have a critical opinion on a technical-economic study of a piece of equipment or a demonstration of ALARP reduction for a particular scenario.

The method relies on the principles of cost-benefit analysis and revolves around the following four stages:

1. Establish a list of possible measures, and estimate their cost. It is important to note that these measures are not only safety barriers, but more generally any measure contributing to reducing the studied risk. We can thus consider risk reductions at the source as well as process changes or changes to the site.
2. Compare between them the measures resulting from the first stage, in order to select the most "cost-effective."
3. For each measure adopted by the second stage, estimate the benefits of its implementation.
4. For each measure adopted by the second stage, perform a cost-benefit analysis.

The method must include a cost-benefit analysis, the purpose of the last stage. The cost-benefit analysis improves the decision-making processes in the areas of safety and the environment. When a project is contemplated, this approach allows for integrating, within the same framework, both the costs that are usually assessed in monetary terms, and the benefits that are not assessed in monetary terms. It should be noted that the term benefit is distinguished here from the term profits, the latter term designating gains that are assessed in monetary terms.

Costs that are usually assessed in monetary terms are for example purchases of equipment or raw materials. Benefits that are not usually assessed in monetary terms are, for example, gains in the area of personal safety, expressed in terms of reducing the severity or the annual probability of an accident occurring.

As indicated in paragraph 1.1, the Circular of May 10, 2010 notes that the projected measures should be analyzed in order to only select those *"whose cost is not disproportionate to the expected benefits [for...] reaching, under economically acceptable conditions, a risk level as low as possible, given the current knowledge and practices and the vulnerability of the environment."* Contrary to what this excerpt suggests, it is not necessary to systematically conduct a cost-benefit analysis for each of the planned measures as this would be too complex to implement. That is why our approach proposes a simpler cost-benefit analysis for the measures adopted at the end of the first stage of the method.

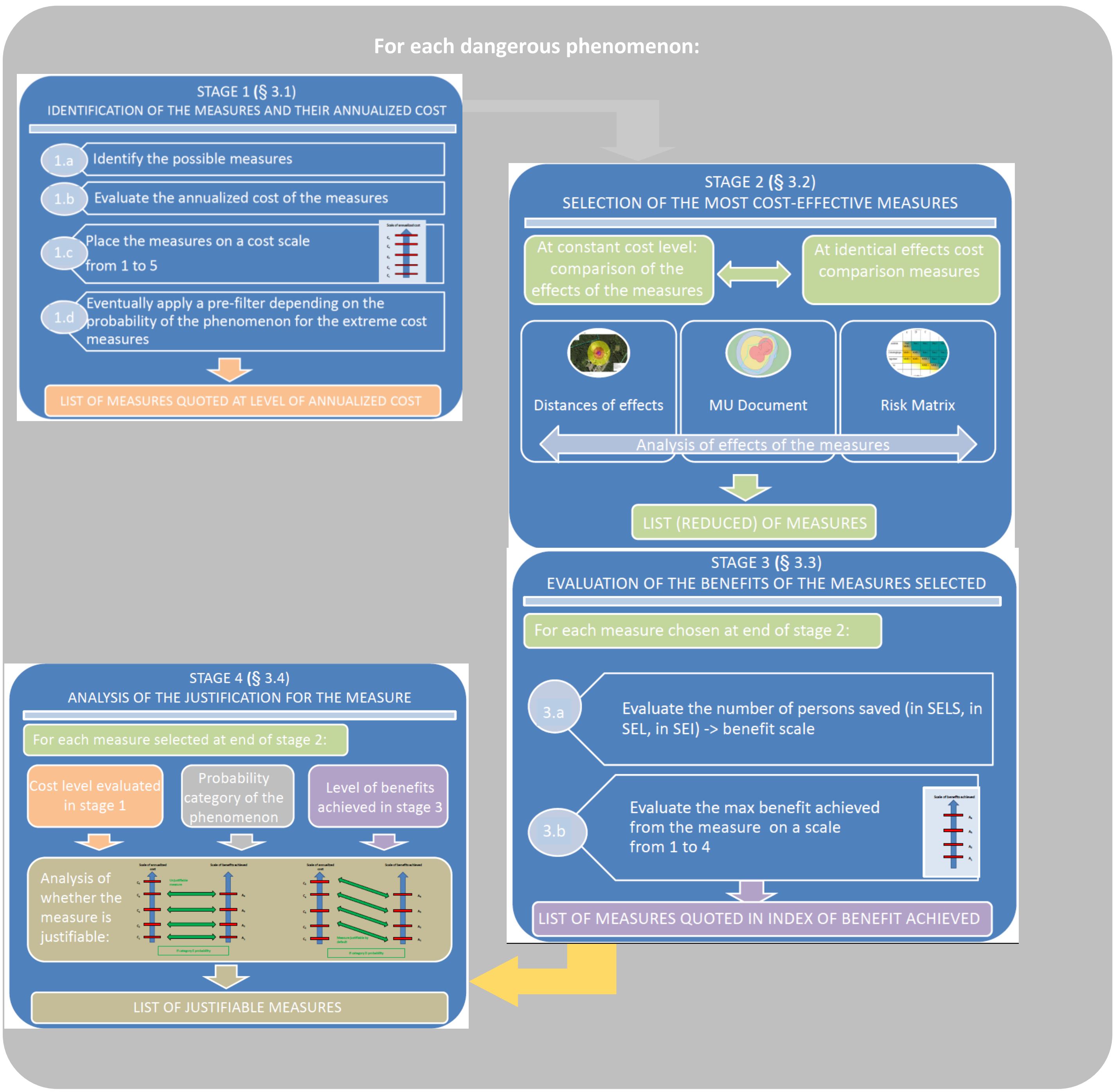
On the other hand, when the stakes so warrant, conducting a cost-benefit analysis can be considered. Items that are relevant to this approach can be found in two guides from the Organization for Economic Cooperation and Development (OECD) [3] [4].

3. PRESENTATION OF THE METHOD

The method for implementing the ALARP principle revolves around four stages. The user must first identify all the possible measures to reduce the risk studied. The user must also calculate the cost of these measures. The projected measures must, secondly, be compared between them to select the most cost-effective ones. Finally, for each measure remaining at the end of the second stage, the benefits of its implementation are compared to its estimated cost during the first stage.

The analysis of the results of this comparison can guide the user's decision in favor of the implementation, or not, of the measures studied.

The general approach is illustrated by the chart below:



3.1 First Stage

The first stage of the method is to list the measures considered to reduce the studied risk, and to allocate a cost level to each of these measures.

3.1.1 Establishing the List of Measures Considered

The risk reduction measures are classified into three categories:

- the measures that make the scenario physically impossible and replace it with one or several others. These are for example changes to the process;
- those that decrease the probability of the scenario and not its severity. These are for example preventive measures;
- those that reduce the probability of the scenario and make possible a second scenario of lower severity. These are for example protective measures.

The list can be established on the basis of professional guides, of state-of-the-art security measures or on the users' experience. The possible measures must be effective and acceptable economically. In regards to the economic acceptability, the ICPE operator is the actor who has the most complete information. We thus recommend, for this list, involving both the inspectors and the manufacturers.

Some measures considered may not be selected at this stage if they are deemed unacceptable from an economic point of view. The analysis of the economic acceptability may rely on some of the following elements:

- the cost of the security measure expressed as a percentage of the turnover;
- the amount of the investments already made concerning security;
- the structure of the industrial sector in which the operator operates. This involves assessing a security measure's ease of implementation. Examples of indicators are:
    - the typical dimensions of installations in the industrial sector (as well as their number) and the relative dimension of the facility and the company compared to other operators in the sector;
    - the lifespan of the industrial equipment concerned.
- the market structure in which the operator operates, which allows for assessing the possibilities for an operator to pass on a cost increase, partially or completely, to its selling prices or its suppliers. Examples of indicators are the size of the market in which the operator operates, the price elasticity of the distributed product, or even the type of competition in the relevant market;
- the operator's ability to absorb the costs of a security measure while ensuring that the installation remains viable in the short, medium and long term. This element can be evaluated for example by using indicators such as "liquidity," "solvency" or "cost-effectiveness".

3.1.2 Estimate of the Cost of the Security Measures

The cost of each previously-listed security measure must be assessed. To achieve an accurate assessment, it is important not to forget all of the future costs and savings associated with the measure's implementation over its estimated lifespan. These costs and savings are reduced to an annualized cost, or average annual cost. This allows us to quickly compare, on the one hand, the measures against one another, and to quickly compare, on the other hand, the measures with the annual profits related to their implementation.

To estimate the annualized cost, the user can use various sources such as modelings, quotes, feedback from experience, expert advice, etc. A detailed approach can rely on the following expression of the annualized cost of a new security measure:

$$annualized\ \text{cost} = \sum_{t=1}^{n} \frac{(C_t + OC_t)}{(1+r)^{t-1}} \left[\frac{r(1+r)^{n-1}}{(1+r)^{n} - 1} \right]$$

Where:

n = estimated lifespan of the measure under consideration;

t = index ranging from 1, year of the measure's implementation, to n;
C_t = total investment costs for the security measure over the year t;
OC_t = total net cost of operation and maintenance of the security measure over the year t;
r = discount rate.

For the estimate to be accurate, the costs must be itemized as much as possible. They should also take into account the possible savings that would be generated by establishing the security measure, for example the energy savings. If the user does not have all the necessary information, simplifications can be made; however, the recommendations produced by the method will be less robust. If for example the operating and maintenance costs are forgotten, the cost of the measure will be underestimated. If the discount rate is unknown, it may be taken as equal to 10% by default in this initial version of the guide. The rate will, by default, be studied in more detail in the next version. Usage examples and additional information on calculating the annualized costs under this formula are given in Appendix 1.

The user can also deliberately choose to simplify the cost estimation if the barriers that he is considering have very different costs and he knows in advance that the benefits of setting up these barriers will be very similar.

During a cost estimate, several points should be given special attention:

- **the homogeneity of the unit for expressing the costs:** there may be multiple sources that estimate the costs of the various elements; thus, various units of monetary value may be used. In the context of a cost estimate, these values must be homogenous and be expressed for a single benchmark year and in a single currency. Changes in prices and exchange rates must in particular be taken into account;

- **the estimate of the lifespan of the measure under consideration:** this parameter can have a significant impact on the estimate of the annualized cost, and it is important to estimate it correctly. The life expectancy varies according to the measures under consideration (displacing the tank, establishing a retention basin, adding a gas detection sensor, etc.). The selected value is capped by the facility's lifespan. A maximum of 30 years may be selected by default;
- **the discount rate:** the discount rate is linked to the interest rate, which reflects a stakeholder's cost of capital. This differs according to the stakeholder concerned. It can also take into account the risks incurred by the project. The user must select the most appropriate interest rate, corresponding in the majority of cases to its financing rate, but he must justify his choice. Use of actual interest rates that take into account the changes in prices is recommended;
- **integrating the implementation of the security measure into the facility's maintenance cycles:** to minimize the cost of installing the security measure, it would be wiser not to implement these measures except during normal stoppages for the facilities' maintenance.

3.1.3 Positioning of the Measures on a Qualitative Scale of Costs

We propose to position the annualized cost estimated in the previous paragraph on a qualitative scale with 5 levels. This positioning will eventually allow for applying an initial decision-making filter on certain measures with extreme costs depending on the category of probability of the hazardous phenomenon being studied.

The positioning will allow at the 2nd stage a simple comparison of the annualized costs of the measures with the benefits induced by their implementation.

The proposed scale is as follows:

Table 1: Proposal for Qualitative Scale of Costs

Cost level	Annualized cost
1	Less than €10,000
2	Between €10,000 and €50,000
3	Between €50,000 and €250,000
4	Between €250,000 and €1,000,000
5	Greater than €1,000,000

<u>Note:</u> this scale of costs is a proposal that will be changed in a future version of this guide. Currently, some levels are very spread-out (such as cost level 4 that covers a range of €750,000). We therefore advise the user to be prudent and reasonable when using the scale of costs in the rest of the method. If, for example, a measure costs €300,000 and another measure costs €900,000, this will need to be kept in mind during the 2nd stage of the method.

In the third stage, the benefits of implementation are evaluated on qualitative scales to allow a quick comparison. We have however chosen not to convert these benefits into monetary equivalents so as to ensure that objectives scales are more visual. For this same reason, the annual probability of occurrence of the hazardous phenomena is not directly included in the scales, although the reduction in the annual probability of occurrence constitutes an advantage. It was, however, taken into account to determine the method as a whole; this is outlined in Appendix 2.

As previously stated, a pre-filter can be applied based on the probability of the accident on which the method is applied:

- If the probability of the accident is category E, we recommend considering all the cost 5 measures as disproportionate, and to not pursue the method for these measures. If, however, the user does not wish to exclude them, they may be the subject of following stages. In this case, they shall be considered as cost 4 measures during the results analysis (paragraph 3.4).
- If the probability of the accident is category D, we recommend implementing all the cost 1 measures. However, if the user does not wish to apply them in a systematic manner (for example if there are few sensitive issues around the site, or few benefits are expected), they may be the subject of following stages. In this case, they shall be considered as cost 2 measures during the results analysis (paragraph 3.4).

3.2 SECOND STAGE: SELECTING THE MOST COST-EFFECTIVE MEASURES

The purpose of this stage is to compare the measures against each other to perform an initial filtering of the most effective measures. This does not however involve comparing here the benefit of implementing a measure with cost savings if it is not implemented; this will be the subject of the third stage. This comparison should be used with caution if the measures have very different estimated lifespans.

The comparison can take two forms:

- **Comparisons between measures are done at a given cost.** We do not compare the benefits of various costs measurements; we are content to select at this stage the most effective measures for each cost level, i.e. those that minimize the risks most.
- **Comparisons of measures are done at identical consequences.** At this stage we select the least expensive measures from among those leading to identical consequences in terms of risk. For example, if measures with different cost levels have the same benefits (typically two measures that eliminate the effects beyond the property boundaries), it is possible to eliminate the most expensive measure by considering that it is less cost-effective than the other.

The consequences in terms of risks can be evaluated using different media. We offer 3 types of comparisons, based on the distances effects, on the mastery of the urbanization that is appropriate to the case study, and on a frequency/severity grid. These comparisons can be used independently or in a complementary manner depending on the measures under consideration (prevention or protection measures, measures of change in process, etc.). The information from these comparisons is then analyzed, where appropriate, in order to select the measures.

According to the study's purpose, the user can use one or more of these comparisons.

3.2.1 Comparison based on Distances Effects

The comparison based on distances effects can be quickly implemented and easily understood, but does not take into account the potential reductions in probability of accidents due to the measure's implementation. It also does not take into account the creation of additional scenarios. However, we recommend using it when the measures to be compared are all protective measures. In this case, the comparison must be made on the reduced severity scenarios, i.e., when the protective barrier works (see Appendix 3).

This comparison does not include the probability of failure of the measures under consideration; as such it can be used to compare measures with similar level of confidence but must be used with vigilance in the case of measures with various levels of confidence and reducing the severity by at least a factor of 10.

A comparison based on the distances effect consists of comparing the benefits of several measures on the same cartographic medium. As part of a safety report, the zoning of the effects is a suitable tool for this comparison; we therefore recommend using it.

For each cost level, the measure is selected that leads to the largest reduction of distances effects. In some cases, the reduction of the distances effects is not linear: one can imagine a measure reducing the area of significant lethal effects without reducing the other effects distances, and another at the same cost level reducing the area of lethal effects without reducing the other two. For these cases, the user will be able to rely on the sensitive issues present in the areas of effects to guide his choice of measure to be selected.

3.2.2 Comparison based on the Land Use Planning Document

If the method is used for scenarios involved as part of a Technological Risk Prevention Plan (PPRT) or a French “Porter à Connaissance” (PAC), the user can choose to make this comparison of measures based on the associated zoning maps (hazards zoning or PAC zoning). The approach is then the same as before: it involves comparing, for measures with the same cost level, the maps resulting from implementing these measures. Directly comparing the zoning maps allows for taking into account the probabilities of the accidents, but the comparison may be less obvious than with areas of effects: one can imagine reducing the zoning constraints on one area, but increasing them on another. This is for example the case for moving equipment. We advise the user to think in this case in terms of mastery of the urban planning: what are the most sensitive issues? Does the measure's implementation reduce the hazards to which they are exposed?

The comparison on the land use planning document (PPRT or PAC for example) is therefore also very visual, and allows us to think directly in terms of urbanization objectives. In particular, studying the effect of a measure's implementation on this medium provides a broader vision of the reduction of the overall risk level of the site studied, as all the major accidents are aggregated here. In return, it will be more difficult to directly observe the measure's effect on the scenario studied. To do this, we recommend not automatically using this comparison, but instead when the user's goals are oriented towards land use planning.

This comparison allows us to visualize the potential impact of any type of measures (preventive and protective, process modification measures). If the measure allows dismissal of a phenomenon of the land use planning process, this will result in a change to the maps.

3.2.3 Comparison based on a Frequency/Severity Matrix

A comparison on the grid frequency/severity is more complex to implement, but it is more accurate. In addition, it allows for taking into account changes in annual probabilities of occurrence of the studied scenario, such as for the preventive barriers. Finally, it can explicitly address any new scenarios created by the measures under consideration, for example during operation of a protective barrier, or for the process modification type measures.

In this paragraph, the accident scenarios resulting from the measure's implementations identified in the first stage are called residual scenarios. The comparison consists of positioning the major accident investigated, and all of the residual scenarios, on a probability/severity grid. Then, we count by how many boxes each measure has moved the accident on the grid, whether in probability or severity, in order to compare the measures against one another.

As specified in paragraph 2, the method relies on the probability and severity scales of the Order of September 29, 2005, but it rather targets accidents of probability category D or E, and of "catastrophic" or "disastrous" severity. The accidents that the method will be applied to are therefore concentrated in a few extreme cases on the MMR grid. For this reason, it seems unwise to directly use these scales to make the comparison: the significance will be low because the boxes cover ranges of probability and severity that are too broad.

We therefore propose dividing the 5 levels of severity of the Order of September 29, 2005, and redefining the categories of probability of this same Order. The choices that led to these re-drawings are tracked in Appendix 3.

3.2.3.1 Assessment of the Levels of Severity

The principle adopted is as follows:

- to reduce the skewing[3] related to use of the grid, we propose using a different counting method for the severity than that in the Decree of September 29, 2005. The proposed approach is to combine the exposed people in the 3 areas of effects to get an equivalent number of people exposed to irreversible effects. We repeat the Order's logic by considering that a person present in the SELS (5% lethality zone) is equivalent to 10 people present in the SEL (1% lethality zone), and that a person present in the SEL is equivalent to 10 people present in the SEI (irreversible effects zone).

  The user must be careful not to count the exposed people twice, given that we choose here to cumulate them, unlike the approach adopted by the Decree of September 29, 2005. Thus, it is proposed to calculate to determine the level of severity the following equivalent number:

  $$N_{éq\ SEI} = 100\, n_{SELS} + 10\, (n_{SEL} - n_{SELS}) + (n_{SEI} - n_{SEL})$$

  or $N_{éq\ SEI} = 100\, n_{SELS} + 10\, (n_{SEL} - n_{SELS}) + (n_{SEI} - n_{SEL})$

  With:

  $N_{éq\ SEI}$ the equivalent number of people exposed to the irreversible effects;

  n_{SELS} the number of people exposed to the significantly lethal effects;

  n_{SEL} the number of people exposed to the lethal effects;

[3] *Threshold effects related to the normal counting of the severity can lead to eliminating measures at this stage, although they would achieve higher thresholds of people saved during the 3rd stage.*

n_{SEI} the number of people exposed to the irreversible effects.

These numbers of exposed people must be calculated in the disks of effects and not in the crowns simply so that the previous formula is used.

- the equivalent numbers of people exposed in the SEI are then divided into 10 levels as shown in the following table.

Table 2: Finer Severity Grid

Severity level	Equivalent number of people in the SEI
10	More than 3,000 people exposed
9	3,000 or fewer exposed people
8	1,000 or fewer exposed people
7	300 or fewer exposed people
6	100 or fewer exposed people
5	30 or fewer exposed people
4	10 or fewer exposed people
3	3 or fewer exposed people
2	1 exposed person or fewer
1	0.3 or fewer exposed people

3.2.3.2 Assessment of the Frequency Levels

With this method, we do not recommend using the categories A to E of the PCIG Order directly for the annual probabilities of occurrence of the hazards. We recommend instead relying on the commonly used frequency categories: it is said that a dangerous phenomenon is of category Fn if its frequency of occurrence is in the range of $[10^{-n-1}/year; 10^{-n}/year[$. For more information on the frequency categories, the user can refer to the report "Integration of the Probability in Safety reports: Practical Guide" [5].

For consistency with the Refined Severity Grid presented in Table 2, we propose dividing each frequency category in two, a "more" category corresponding to the upper half of the range, and a "less" category corresponding to its lower half:

Table 3: Finer Frequency Grid

Frequency category	Associated Range	Qualitative interpretation
$F0+$	[3.16,10^{-1} /*year*; 1/*year*[	Between 1 time every 3 years and 1 time per year
$F0-$	$[10^{-1}/year; 3{,}16.10^{-1}/year[$ [10^{-1}/*year*; 3.16,10^{-1}/*year*[	Between 1 time every 10 years and 1 time every 3 years
$F1+$	$[3{,}16.10^{-2}/year; 10^{-1}/year[$ 3.16,10^{-2}/*year*; 10^{-1}/*year*[	Between 1 time every 30 years and 1 time every 10 years
$F1-$	$[10^{-2}/year; 3{,}16.10^{-2}/year[$ [10^{-2}/*year*; 3.16,10^{-2}/*year*[	Between 1 time every 100 years and 1 time every 30 years
…	…	…
$Fn+$	$[3{,}16.10^{-n-1}/year; 10^{-n}/year[$ [3.16,10^{-n-1}/*year*; 10^{-n}/*year*[	-
$Fn-$	$[10^{-n-1}/year; 3{,}16.10^{-n-1}/year[$ [10^{-n-1}/*year*; 3.16,10^{-n-1}/*year*[	-

Note: It is theoretically possible to have negative frequency categories, e.g. F(-1), which correspond to events occurring more than once a year. We, however, chose not to represent them in the preceding table because such high frequencies are unlikely for hazardous phenomena.

3.2.3.3 Analysis of the Gain on the Finer Matrix

The major accident investigated and all the residual scenarios should be evaluated in the refined scales of Table 2 and Table 3. The user must then place the scenarios, before and after the measure's implementation, on a frequency severity grid based on these two scales. It shall then count, for each measure, the number of boxes that the accident has moved following the measure's implementation. It should be noted that the columns of the grid are not fixed because the frequency scale is unlimited. It is up to the user to tailor the columns' frequency categories to his case study.

Let AM be the major accident studied, and Mi the residual scenario resulting from the implementation of measure i; hereinafter is an example of frequency/severity matrix and positioning:

Table4: Example of Refined Frequency/Severity and Positioning Matrix

	F6 −	F6 +	F5 −	F5 +	F4 −	F4 +	F3 −	F3 +
10		M1		3 boxes	AM			
9								
8				4 boxes				
7				M3		5 boxes		
6								
5					M2			
4								
3								
2								
1								

On this example, measure 1 has moved the accident by 3 boxes, by only reducing its frequency of occurrence. Measure 2 moved the accident by 5 boxes, by only reducing its severity. Measure 3 moved the accident by 4 boxes, 3 on the severity scale and 1 on the frequency scale.

We propose to then select, for each cost level, the measure that helped to move the accident by the largest number of boxes. On the example of Table 4, if all three measures are at same cost level, measure 2 is then the one that has the best risk reduction. It is therefore selected for the third stage.

Notes:

- In the case of a measure that has more than one residual accident, such as a protective measure, the user must place all the residual accidents and calculate each distance. The distance associated with the measure corresponds to the shortest distance of all. The reader can refer to Appendix 3 for more details.
- If several measures at the same cost level reach the greatest distance, the user may choose either to select the one that appears to him to be the most relevant, or to keep them all for the next stage.

- The measurement may improve the acceptability requirements, allowing for example to exclude an accident from the cumulative MMR rank 2 rule for a Seveso facility.

3.3 Third Stage: Evaluation of the Benefits of the Measures

For each measure adopted at the end of the second stage, we propose to evaluate the benefits of its implementation on scales with 4 levels. It should be recalled here that we are talking about benefits and not profits, as the issues spared in implementing the measures are not monetized (see paragraph 2).

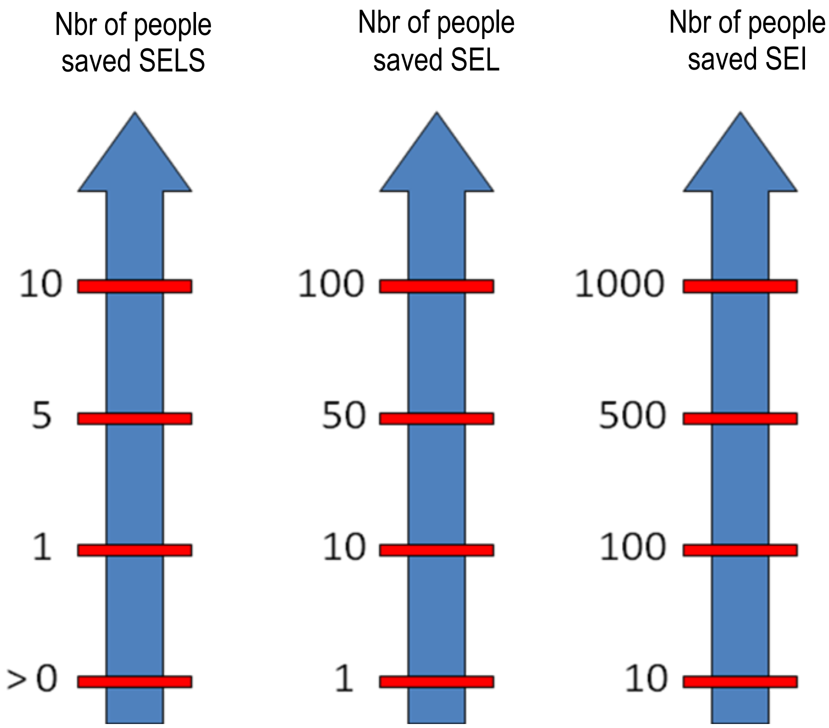
In the case of a measure creating multiple residual scenarios, typically a protective measure, we have taken the position of only estimating the benefits of the residual scenario with the lowest severity (see justification in Appendix 2).

In the case of a preventive measure, we propose considering that the residual scenario (with decreased frequency but with the same severity) is equivalent to a scenario of the same frequency and of reduced severity of the same factor (for example, for an NC1 protective measure, the severity would be divided by 10).The benefit is therefore rated by severity delta (e.g., benefit equal to 9/10 of the original severity)

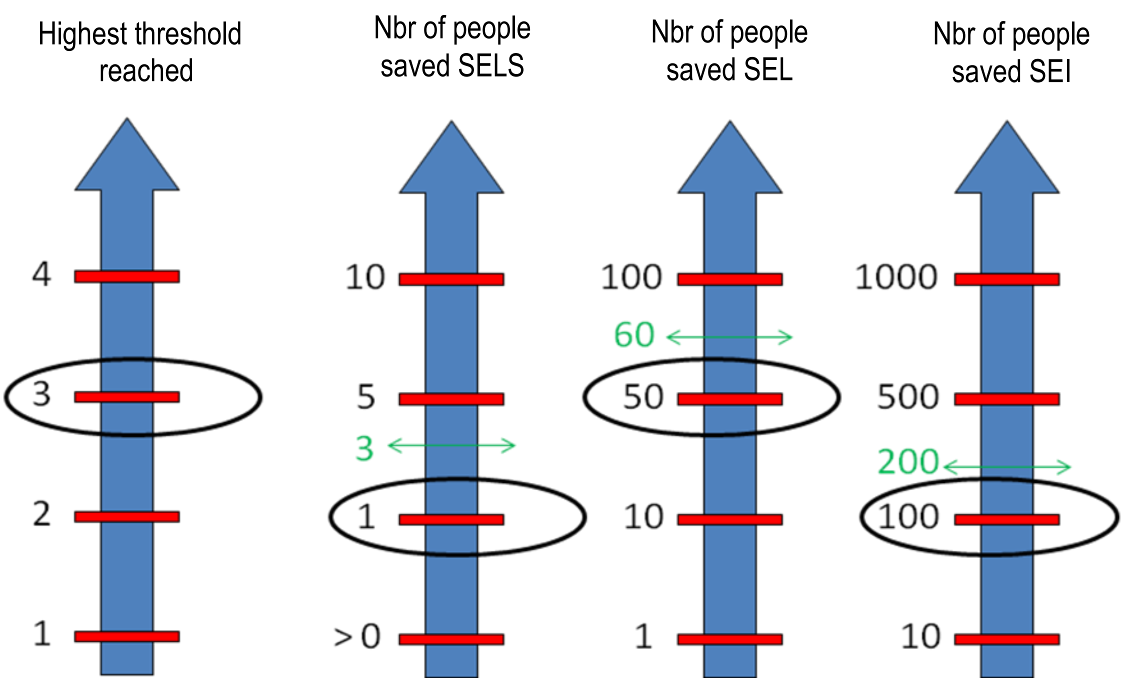
At this stage, we propose three benefits scales. They relate to the **human issues**: the number of exposed people saved for each of the three intensity levels. **It involves the difference between the number of people present in each area of intensity before and after implementation of the measure.**

The benefits associated with the implementation of a measure are represented on scales to facilitate the users' understanding of the method and the analysis of the results of this stage, detailed in paragraph 3.4. The thresholds of these scales have been calibrated on some actual cases we studied (see Appendix 6).

The scales that we propose are as follows:



At the end of this stage, we adopted for each measure the highest threshold reached on at least one of the benefits scales. If for example a measure saves 3 people in the area of significant lethal effects, 60 people in the area of lethal effects and 200 people in the area of irreversible effects, the highest threshold reached is the 3rd level, out of 4 possible:



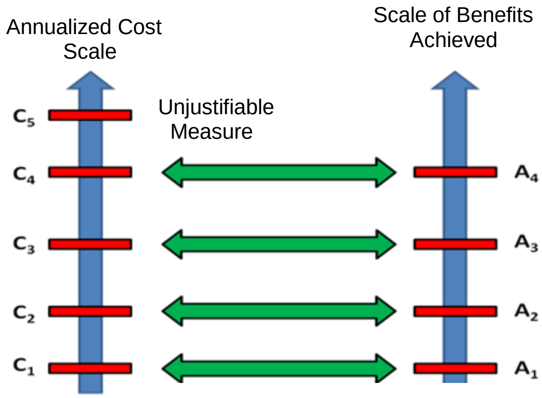
3.4 ANALYSIS OF THE RESULTS

For each measure, the maximum threshold of benefits reached determined in the third stage must at this stage be compared to the cost level of this measure.

The proposed rule depends on the category of probability of the initial phenomenon studied:

- If the major accident to which the method is applied is category E, **we recommend implementing the measure as soon as the maximum benefit threshold reached is greater than or equal to the measure's cost level**. If this threshold is strictly lower than the cost level, it is recommended to not implement the measure.

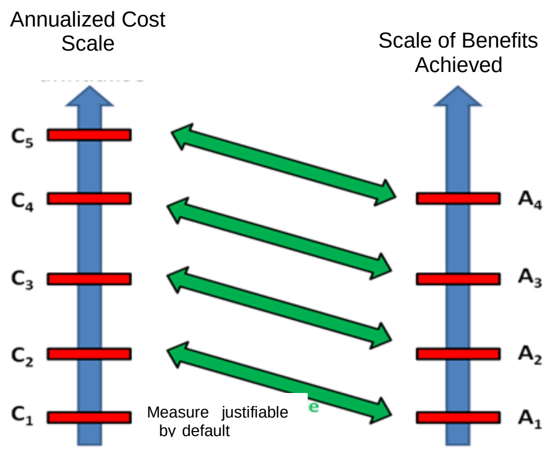
  Note: The cost 5 measures that have not been considered by default as disproportionate shall be considered cost 4 at this stage (see paragraph 3.1.3).



If probability in Category E

- If the major accident on which the method is applied is category D, **it is recommended to implement the measure as soon as the maximum threshold reached is greater than the measure's cost level minus one**: at equal benefits, we can recommend measures at a higher cost level if the major accident is category D. The measures recommended in this way are said to be justifiable.

  Note: the cost measures 1 that have not been considered by default to be justifiable shall be considered cost 2 at this stage (see paragraph 3.1.3).



If probability in Category D

Different qualitative elements may however be taken into account to guide the user's decision towards a different choice from the one recommended *a priori* by the method:

- The benefits estimated on the scales in paragraph 3.3 are not aggregated. We only adopt the maximum threshold reached on one of the benefits scales. If this threshold is reached on several scales at the same time, and the method considers the measure as unjustifiable, the user can choose to adopt it anyway.
- When significant changes in the production process, the reconfiguration of the facility or the heavy equipment are studied, the capital investments can be significant. An early reconfiguration and a review of the processes can be expensive for an operator, in particular when it comes to equipment with a long service life. Scheduling the implementation of new security measures to coincide with the existing replacement and investment cycles can be an effective way to implement the safety measure in a cost-effective manner. If a measure is considered unjustifiable by the method, the user can therefore consider implementing it anyway in the context of the facility's modernization plan.
- If a measure is considered unjustifiable, but it reduces the likelihood or severity of other major accidents than the one studied, it could make it justifiable by valuing the action on these other accidents. This can be done qualitatively by the user's judgment, or quantitatively by accumulating the benefits of the measure on the various scenarios it impacts.

The method remains a decision support tool and its results are to be put into perspective with the local context. In addition, it is not necessarily exclusive in its recommendations: several measures may prove to be justifiable at the end of the third stage. In this case, the user may favor the measure that to him seems best suited to the case study.

4. PRACTICAL CASES OF USE OF THE METHOD

The two practical cases presented here are fictitious. The measures proposed, their costs, the severities and the recommendations are given for purely illustrative purposes.

4.1 FIRST PRACTICAL CASE

4.1.1 Presentation of the Case

When updating his safety report, the operator of a flammable liquid depot has a major accident, the UVCE following the loss of containment of a gasoline tank located on the site borders, in an E/disastrous case on the MMR grid. In order to ensure that he can no longer reasonably reduce the risk of this accident, he decides to apply the method proposed in this guide.

The characteristics of the studied accident are:

Threshold	Distance	Number of people exposed
SELS	50 m	25
SEL	70 m	25
SEI	150 m	30

4.1.2 First Stage: List of Measures

The operator is considering 3 measures to reduce the UVCE risk:

1. Reduce the surface area of the retention basin; this measure reduces the severity;
2. Set up a double wall on the tank; this measure eliminates the studied accident and replaces it with 2 others: the UVCE in height (double wall full of liquid) and the UVCE for the volume contained within the double walls; these two accidents have the same frequency as the original, and lower severities;
3. Dismantle the tank and rebuild it farther from the property boundaries; this measure eliminates the studied accident and replaces it with another, with same distances effects but of different origin.

Having already made a calculation of the cost of measure 3 on another of its sites, the operator knows that it is cost level 5. However, he is unsure how much it would cost him to implement one of the first two measures, and must do a detailed calculation.

Estimate of the Cost of the M1 Measure - Reduction of the Surface Area of the Retention Basin:

The various components of the total annual costs are estimated by the manufacturer:

- total investment costs for the security measure = €500,000 in year 1;
- estimated lifetime of the security measure = 30 years;
- selected discount rate: 10%;
- total net cost of operation and maintenance of the security measure: €0

The annualized cost (here C_a) is therefore given by:

$$C_a = \frac{500\ 000}{(1+0{,}1)^0} \times \frac{0{,}1 \times (1+0{,}1)^{29}}{(1+0{,}1)^{30}-1}$$

$$C_a = 58\ 700\ €$$

The M1 measure is therefore cost level 3: the total annual cost is between €50,000 and €250,000.

Estimation of the Cost of the M2 Measure - Implementation of a Double Wall on the Tank:

The components of total annual costs are estimated by industry as follows:

- costs of total investment from the security measure = €2,500,000 in year 1;
- estimated lifetime of the security measure = 30 years;
- selected discount rate: 10%;
- total net cost of operation and maintenance of the security measure: 0.5% of the investment per year.

The annualized cost (here C_a) is given by:

$$C_a = \left[\frac{2\ 500\ 000}{(1+0{,}1)^0} + \sum_{t=2}^{30} \frac{0{,}005 \times 2\ 500\ 000}{(1+0{,}1)^{t-1}}\right] \times \frac{0{,}1 \times (1+0{,}1)^{29}}{(1+0{,}1)^{30}-1}$$

$$C_a = 307\ 252\ €$$

The M2 measure is therefore at cost level 4: the total annual cost is between €250,000 and €1,000,000.

Estimation of the Cost of the M3 Measure - Displacement of the Tank:

The M3 measure has a cost level 5: its annualized cost is greater than €1 M.

The list of the measures under consideration and their characteristics are summarized in the following table:

Measure	Cost level	Comment
M1: Reduction of the surface of the basin	3	UVCE frequency unchanged, severity reduced.
M2: Double wall	4	2 accidents, same frequencies, the effects no longer go beyond the site
M3: Movement of the tray	5	Same frequency and same distances effects, but the cause of the accident is misplaced: the effects are now contained within the boundaries of property

The M3 measure is at cost 5. The method therefore recommends not to adopt it because the UVCE is category E. The manufacturer therefore considers it too expensive and only applies the following two stages to the first 2 measures.

Note: the M3 measure could be adopted if the previous filter was not applied. In this case, this stage would eliminate it all the same. Indeed, the M2 and M3 measures have the same advantages since they both eliminate the effects beyond the property boundaries. However, the M3 measure is more expensive than the M2 measure and the comparison of the costs levels to the equivalent benefits thus eliminate it.

4.1.3 Second Stage: Selection of the Most Cost-Effective Measures

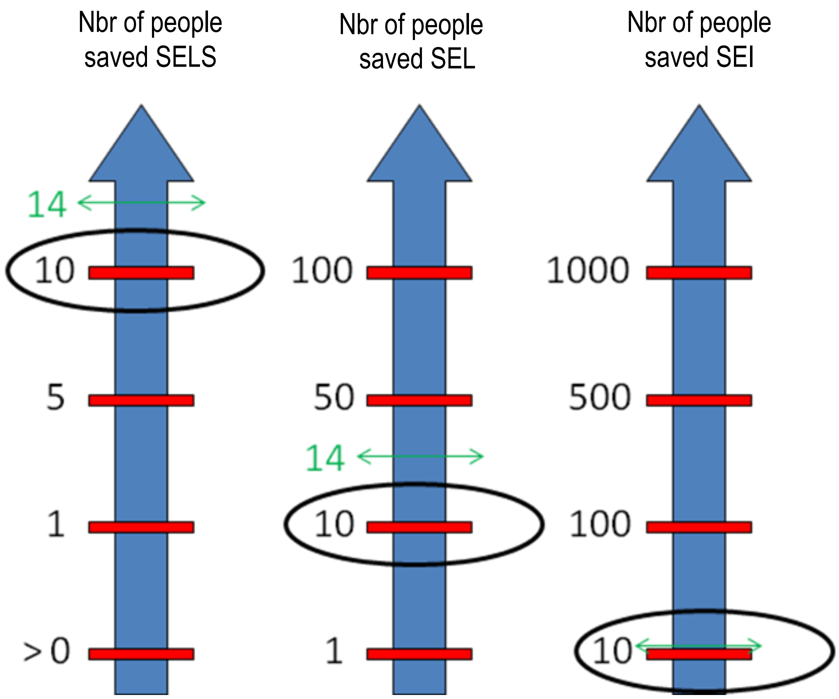
The 2 measures having different costs and benefits, this stage has no place here, and we can go directly to stage 3.

4.1.4 Stage 3: Assessment of the Benefits

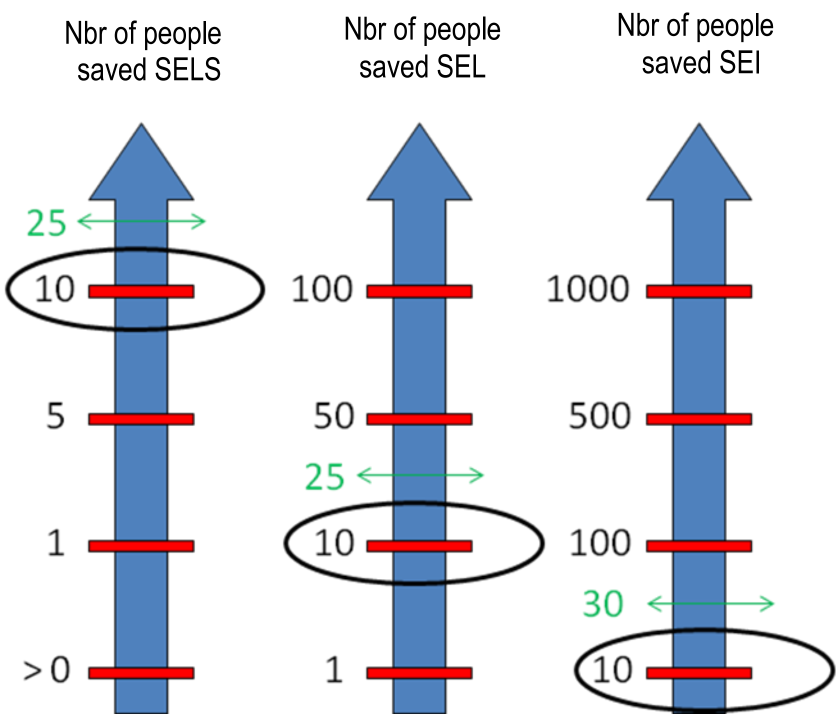
The M1 measure does not change the frequency of occurrence of the UCVE. The number of people saved by this measure is calculated in the following table:

Area of effect	Number of people exposed without M1	Number of [people] exposed with M1	Number of people saved by M1
SELS	25	11	14
SEL	25	11	14
SEI	30	20	10

The M1 measure thus achieves the maximum threshold on the benefits scales:



The M2 measure limits the effects within the site, thus saving all the people who were present in the areas of effects. The measure thus reaches the maximum threshold on the benefits scales:



4.1.5 Fourth Stage: Analysis of the Results

The UVCE is category E, and the M1 and M2 measures achieve the 4^{th} level on the benefits scales. As they are respectively at cost levels 3 and 4, the method considers them both justifiable. The operator has here the choice to implement the measure that seems to him to be the most suitable, the method alone not allowing him to arbitrate for one more than the other.

The M1 measure makes it possible to reduce the number of people exposed in the SELS and the SEL by more than half. On the other hand, the implementation of this measure does not reduce the severity of the associated hazards: it remains in disastrous because of the residual number of people in the SELS (more than 10).

The M2 measure allows you to completely remove the accident from the MMR grid but is significantly more expensive. Here, for reasons of image, the operator may choose to implement the second measure, setting up a double wall.

4.2 SECOND PRACTICAL CASE

4.2.1 Presentation of the Case

An inspector of classified installations studies the safety report of a Seveso low threshold site. This site includes an unloading station, which generates the scenario with the greatest distances effects, the rupture of an unloading arm for example. This scenario is category D, with effects distances and number of exposed people as follows:

Threshold	Distance	Number of people exposed
SELS	200 m	0
SEL	250 m	0
SEI	1,350 m	10

The inspector wishes to have a critical opinion on the choice of the measure adopted by the manufacturer, and therefore applies the method proposed in this guide.

4.2.2 First Stage: List of Measures

Using his experience on a very similar site, the manufacturer proposes four measures to reduce the risk associated with the unloading station:

1. Establishment of a flow-restricting orifice; this reduces the distances effects without reducing the frequency of the accident; however the effects in case of rupture of the arm are slight due to the fact that it does not reduce the tank side flow;
2. Semi-confinement of the unloading station with establishment of a water curtain; this measure leads to two residual scenarios, one of reduced frequency and of

the same severity if the measure does not work, and one of the same frequency and of lower severity if the measure works;

3. Total containment of the station with washing column position; this leads, as the second, to two residual scenarios;
4. Total containment of the station with extraction to a chimney; this measure also leads to two residual scenarios.

The inspector asked the manufacturer to make an estimate of the cost to implement these measures. Using calculations similar to those of the first practical example, a cost level was awarded to each measure. In parallel, the residual scenarios for each measure were modeled. The results are shown in the following table:

Measure	Cost level	Category of POA	SELS Distance (m)	SEL Distance (m)	SEI Distance (m)
M1	1	D	-	50	600
M2	3	D	-	180	450
		E	200	250	1,350
M3	4	D	-	-	-
		E	200	250	1,350
M4	4	D	-	-	100
		E	200	250	1,350

The major accident studied is probability category D.

The M1 measure, the flow restricting orifice, being in cost 1, the inspector chooses in accordance with the method to adopt it as automatically justifiable without needing the two following stages.

4.2.3 Second Stage: Selection of the Most Cost-Effective Measures

Only the M3 and M4 measures are the subject of this stage, because these are the only ones to share the same cost level. A qualitative comparison is sufficient here, as M3 and M4 are protective measures. A comparison of the residual scenarios in case the measures work is therefore to be achieved.

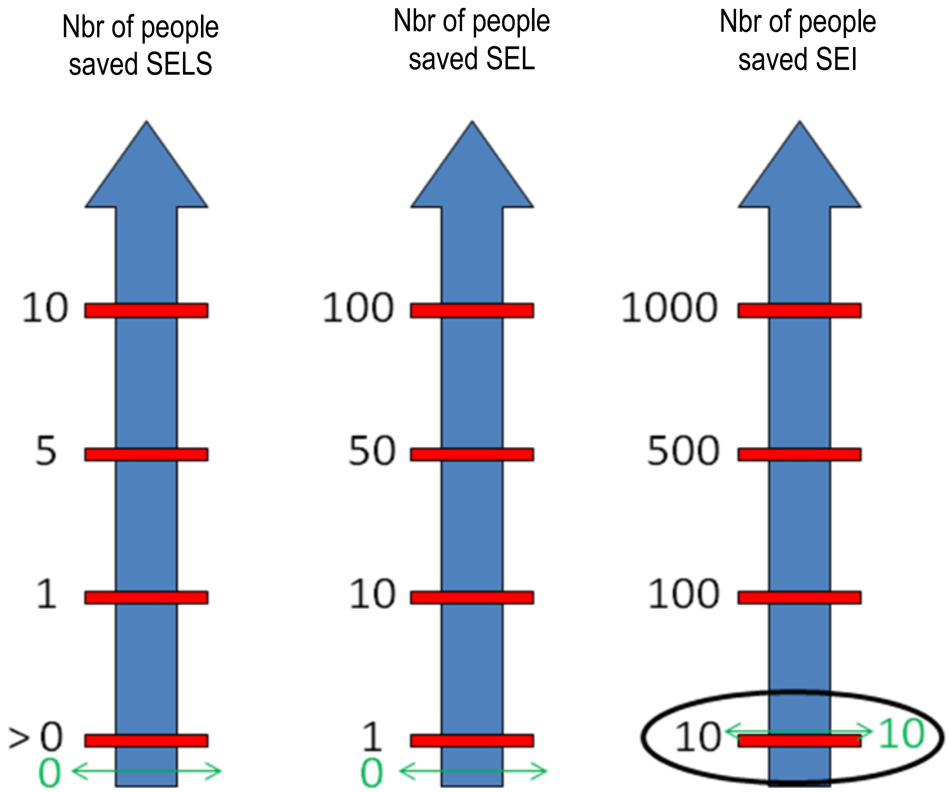
Here the M3 measure eliminates the effects outside the site's boundaries, whereas the M4 measure only reduces the SEI to 100 m. The latter might therefore be rejected as deemed ineffective compared to the third. However, it could be interesting to return to the annualized costs of these two measures. In particular, if the M4 measure is much less expensive than the M3 measure (while still within the cost range 4), the user may choose to adopt it if few issues are present within a radius of 100 m around the studied site. Here, we choose for example to adopt the M3 measure.

Therefore, two measures remain at the end of this stage: the M2 and M3 measures.

4.2.4 Stage 3: Assessment of the Benefits

In this stage, the inspector evaluates in accordance with the method the advantages of the M2 and M3 measures based solely on their residual scenario of lower severity: the one that reduces the SEL to 180 m for the M2 measure, and the one where the SEL doesn't exceed the property limits for the M3 measure.

The two measures exclude 10 people present in the SEI from the areas of effects. The advantages of both measures are therefore the same on the 3 scales of human issues, exceeding the first level but not reaching the second:



4.2.5 Fourth Stage: Analysis of the Results

The maximum threshold reached by the M2 and M3 measures is the first level. The method recommends only implementing these measures if their cost levels are less than or equal to 2, because the major accident studied is category D. Here, measures are cost 3 and 4. The inspector therefore chooses not to impose them on the operator. Only the first measure envisaged, the flow restricting orifice, is finally implemented.

5. CONCLUSIONS AND PROSPECTS

The method proposed in this guide is a decision-making support tool for the implementation of an additional measure to reduce the risk. It is structured in four stages. The first stage is to prepare a list of possible measures and to assign them a cost level between 1 and 5. The second stage compares the measures to each other to adopt the most cost-effective. The third stage estimates the benefits associated with implementing each measure resulting from the 2nd stage. The fourth stage indicates, for each measure, whether it is economically feasible to implement it or not, by comparing the benefits of its implementation estimated during the third stage to the cost level estimated during the first stage.

It is important to note that the thresholds proposed in this guide, for the costs in the first stage, and the benefits in the third stage, have been proposed on the basis of only a few examples of technical-economic studies in the past. These thresholds could evolve following the implementation of the method on actual current cases, to better meet users' needs. Test cases will be carried out in 2015.

It remains nevertheless that this method provides the following significant benefits:

- It is easily adaptable to the users' various needs. It is indeed a decision-making support tool that takes into account several qualitative parameters such as the economic context, the modernization plan, or even the impact on several scenarios. Furthermore, it fits into the framework of the safety reports as well as that of the PPRT.
- It is very quickly applied once the cost of the measures has been estimated, as shown in the examples. The cost estimates stage is binding, anyway, to any technical-economic study.
- In the third stage of the method, new scales can be added later, depending on the issues identified as important. One can thus imagine a scale on the buildable areas released (as part of a PPRT or a PAC), a scale on the environmental consequences, or even a scale on the damages to the frame. The only difficulty will be calibrating these new scales to case studies. The method's actual application will be unaffected.

To meet the objectives of simplicity of implementation of the method, we adopted some the biases given that need to be kept in mind during its application:

- The costs of the measures are reduced to 5 indices reflecting ranges of possible costs. The method considers that two measures at the same cost level in fact have the same annualized cost, which is wrong in practice. At a same cost level, it is possible to find a measure that is twice as expensive as any other. However, if the most expensive measure barely reduces the severity more than the cheaper one, it will be considered more effective. If such thresholds effects appear in an obvious way, the user can use them to change his decision during the analysis of the results. This comment applies more generally to all the intervals used in the method: the severity and frequency ranges of the quantitative comparison of the second stage, as well as the benefits scales defined in the third stage.

- The annual probability of occurrence of dangerous phenomena is not included in the estimate of the benefits. This choice was made to improve the readability of the benefits scales, in order to directly place the numbers of people saved, rather than some barely understandable annual expectations. However, this choice may create bias in some cases, as Appendix 2 highlights. We accept this limitation of the method since we consider the gain in efficiency and simplicity to be greater than the related loss of information.

Finally, it is interesting to note that the method in this guide does not necessarily recommend only one single measure. The first practical example presented in paragraph 4.1 shows, for example, that two measures may be recommended. The user is then forced to make a decision based on his own judgment. However, we do not see this item as a limit; Indeed, regardless of the method of estimating the costs and the advantages/benefits of a measure, one can always imagine a low-cost measure that somewhat reduces the risk, and another more expensive measure that reduces the risk much more without it being possible to arbitrate in favor of one measure or the other. It is therefore impossible to disregard this aspect of the method.

6. REFERENCES

[1] Flauw Y. (2011) - DRA-11-117405 - 11487A "European Benchmark relative to the Recommendations for Implementation of the ALARP Principle," INERIS

[2] Marcon T., Flauw Y. (2013) - DRA-13-124781 - 02941A "Implementation of the ALARP Principle in the United Kingdom and the Netherlands," INERIS

[3] OECD - "Technical Guidance Document on the Use of Socio-Economic Analysis in Chemical Risk Management Decision-Making," OECD Environmental, Health and Safety Publication, Series on Risk Management No.14, 2002.

[4] OECD - "Cost-Benefit and the Environment, Recent Development," 2006

[5] "Guide for the Integration of Probability in Safety reports - Version 1," INERIS, 2008

7. LIST OF APPENDICES

Reference	***Precise Description***	***N° pages***
1	*Annualized cost estimate*	*2*
2	*Taking the probability into account in the method*	*2*
3	*Details on the second stage: selection of the most cost-effective measures*	*1*
4	*Counting of the severity*	*3*
5	*Calculation of the cleared buildable area*	*2*
6	*Choice of the thresholds for the costs and benefits scales*	*2*

Appendix 1:
Annualized Cost Estimate

General information

Under this approach the costing of the security measure must be annualized. It can rely on the following expression:

$$\textit{annualized cost} = \textit{coût annualisé} = \sum_{t=1}^{n} \frac{(C_t + OC_t)}{(1+r)^{t-1}} \left[\frac{r(1+r)^{n-1}}{(1+r)^{n} - 1} \right]$$

Where:

n = estimated lifespan of the measure under consideration;

t = index ranging from 1, year of implementation of the measure, to n;

C_t = total investment in the security measure over the year t;

OC_t = total net cost of operation and maintenance of the security measure over the year t;

r = discount rate.

Concerning the investment costs, three types of costs are distinguished: the expenses of installation, expenditures for safety equipment and a provision for the investment.

In the installation expenditures, we include in particular:

- the definition, design and planning of the project;
- the purchase of the land if necessary;
- the general preparation of the site (in terms of land);
- the construction and civil engineering work, including the foundations/supports, the building, electrical, plumbing, insulation and painting;
- the expenses for engineering and construction and the installation costs (use of equipment, transport of materials, etc.);
- the costs of selecting suppliers;
- the performance checks;
- the start-up costs;
- the costs related to the working capital;
- the costs of cessation of activity (decommissioning), which must include the residual value of the equipment, i.e., the sale of the equipment or materials comprising it.

In the expenses for the safety equipment, there are:

- the cost of the equipment;
- the auxiliary equipment such as the utilities;
- the instrumentation;
- the transportation of equipment;
- the expenditures relating to changes to the installation (adaptations).

Finally, in the estimates of the investment expenses, a certain sum of money or "investment allowance" is sometimes included to cover the expenses that cannot be accurately estimated.

For the costs of the measure's operation and maintenance, the elements to be taken into account are:

- the increased cost of energy consumption: electricity, petroleum products, gas, coal and any other fuel;
- the materials and costs of the services: spare parts, non-energy utilities (water, chemicals including catalysts, etc.);
- the environmental services: treatment and disposal of waste and wastewater;
- the labor costs: operation, management and maintenance personnel, training on new equipment;
- the fixed operating/maintenance costs (overhead): provisions, insurance, administration.

The implementation of a new technique may also lead to changes in the production process that can in turn lead to cost increases: for example, a decrease in the system's effectiveness or a lower product quality. We call these costs overruns the subsequent costs. They must not be forgotten in the calculation. It is also necessary to integrate the taxes and subsidies related to the measure's implementation.

Appendix 2:
Taking the Probability into Account in the Method

Why is the studied major accident frequency not integrated into the benefits scales?

In the results analysis stage, the user compares an annual cost to an annual advantage. To convert this annual benefit into annual profit, it should in particular be multiplied by the frequency of occurrence of the accident. Not to do so is to assume that all accidents have the same frequency.

We accept this restriction for category E accidents; this is equivalent to assuming that all category E accidents have the same frequency. For category D accidents (or of higher frequency, but it should be noted that the method has not been calibrated for accidents with frequency higher than D), the scales are shifted by a notch to compensate for the 10 times higher frequency, as explained in paragraph 3.4.

However, the various levels of the benefits scales are generally separated by a factor of less than 10. Let us consider two major accidents with the same consequences, one of category of probability E and one of category D, ten times more frequent. For illustrative purposes, in order for a cost 3 measure to be recommended for a category E accident, the number of persons saved SEL must be greater than 50. For a category D accident, 10 is sufficient, i.e., 5 times less, whereas the accident is 10 times more likely. This lag is accepted for two reasons discussed in the following paragraph.

Why are the costs and benefits scales not linear?

From one level to the next in the scale of costs, there is a factor of 4 or 5. For benefits, a factor 2, 5 and 10. As we chose to shift the scale of cost of a notch between categories E and D, one can wonder about the reasons for the non linearity, more precisely why there is a factor of 10 between each level of each scale.

First, the scales would be too extended and all measures/all benefits focused around one or two thresholds. Second, the marginal cost of an exposed person increases, that is to say, the more people saved, the more one is willing to pay to save one more. This can be explained through pictures and the bias of behavior making accidents with many victims very unacceptable.

Why artificially change the severity in the case of a preventive measure?

During the results analysis, it is important to compare the cost of the measure to the reduction in the accident's severity. Beyond the criticality is the product of the probability and the severity of the accident. So if we divide the probability by 100, it is conceptually equivalent to dividing the severity by 100 at constant probability.

Why is only the reduced severity scenario adopted for estimating the benefits in 3rd stage?

We grade P and G the probability and severity of the studied accident. Following the measure's implementation, this breaks down into two residual accidents, one of reduced probability P' and of severity G, and one of reduced severity G' and of probability (P-P').

One reasons with the criticality. For each measure, we compare its cost to the gain in criticality, i.e., PxG - [P'xG + (P-P')xG'] = (P-P')x(G-G'). As P' is equal to P multiplied [by] the PFD of the measure, P-P' ~ P. We are therefore reduced to comparing the cost of the measure with Px(G-G').

As explained in the first paragraph of this Appendix, the probability is hidden in the benefits scales; it is therefore like comparing the cost of the measure to G-g', i.e., exactly the number of people saved by the scenario with the lowest severity (cases where the measure works).

Appendix 3:
Details on the Second Stage: Selection of the Most Cost-Effective Measures

Why is the qualitative comparison often sufficient if there are only protective measures?

A major accident probability P and severity G is considered. You want to compare the effect of 2 protective measures M1 and M2 at the same cost level. There is P1, P2 and G1, G2 the components of the residual scenarios.

The sum of the criticality of the two residual scenarios is expressed by, for each barrier:

Criticality M1 = P1xG + (P - P1) xG1

Criticality M2 = P2xG + (P - P2) xG2

We look at the sign of the difference of the criticality to know which measure is the most effective.

Criticality M1 - Criticality M2 = P1x(G - G1) - P2x(G-G2) + Px (G1 - G2).

If the measures are at the same level of confidence, P1 = P2 and the difference in the criticalities is the sign of G1 - G2, and the qualitative comparison in this case is sufficient.

If the measures are not at the same level of confidence, we have 2 possible cases. If G1 is different from G2 and one of two severities is greater than G/10, the first 2 terms are negligible before the 3rd because P1 and P2 are small before P (they are less than P/10). Only the sign of G1 - G2 is important in this case, thus just the qualitative comparison is sufficient. If however G1 = G2 or G1 and G2 are both less that G/10, then the better of the two measures is the one that lowers the probability the most. The qualitative comparison is in this case also sufficient (although it must be slightly adapted to fit in with the probabilities instead of the severities).

Why cut the severity and frequency into 2 categories?

The severity and order PCIG beaches are too broad. For the frequency, the redistribution is necessary for a displacement of a box in frequency to have the same effect on the criticality as a displacement of a box in severity. This allows us to have a sense of how many boxes we've moved.

Why do we adopt the minimum distances if there are several residual scenarios?

The distance is actually the logarithm of the criticality (to a factor of nearly 2): if we move boxes n to the left or down, we multiply the criticality by $10^{-n/2}$.

If there are several residual scenarios with 2 distances d1 and d2, the criticality is in fact multiplied by $10^{-d1/2} + 10^{-d2/2}$ which is roughly equal to $10^{-min(d1,d2)/2}$.

Appendix 4:
Calculation of the Severity

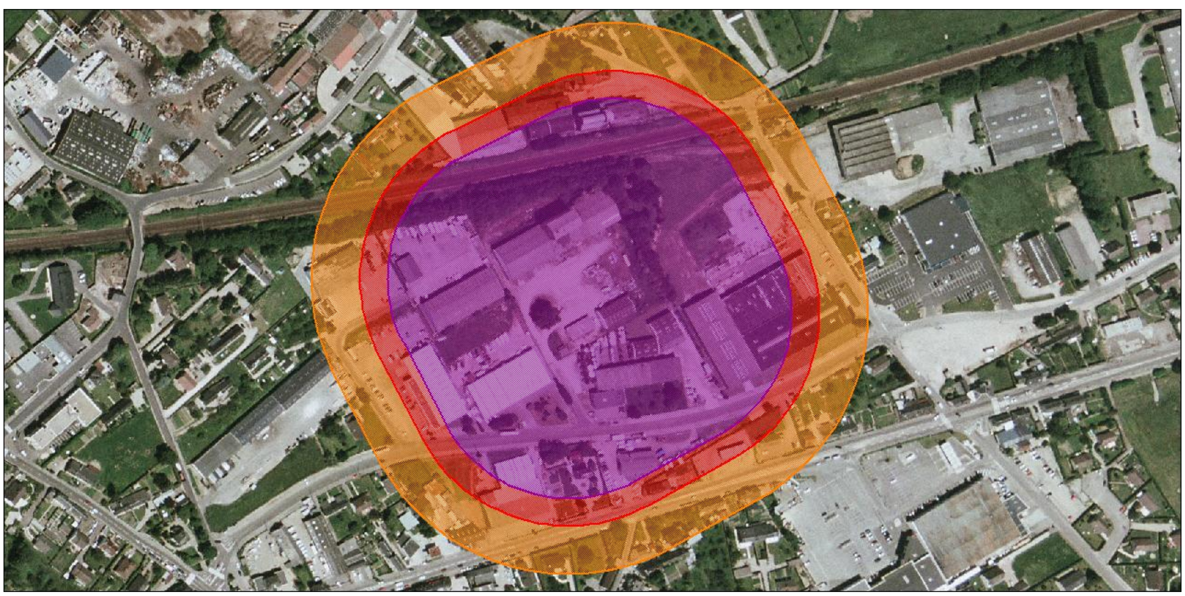
Reminder of the rules for counting the severity:

The Decree of September 29, 2005 specifies determining the number of people potentially exposed to the effects of each dangerous phenomenon in the safety report. This number is then converted to a level of severity, from the most to the least serious: disastrous, catastrophic, significant, serious and moderate, as described in the following table:

Severity level	SELS	SEL	SEI
Disastrous	More than 10 people exposed	More than 100 people exposed	More than 1,000 people exposed
Catastrophic	10 people or fewer exposed	100 people or fewer exposed	1000 people or fewer exposed
Significant	1 person or fewer exposed	10 or fewer people exposed	100 or fewer people exposed
Serious	No casualty	1 person or fewer exposed	10 people or fewer exposed
Moderate	The effects do not exceed the facility's boundaries		1 person or fewer exposed

The final severity level is then the maximum of the three.

Let us consider the following dangerous phenomenon:



The SELS area is the purple disc, the SEL area is the red disc (union of the red crown and the purple disc), and the SEI area is the orange disc (union of the orange crown, the red crown and purple disk).

The regulations introduced the previous table without specifying if it counts among the discs or the crowns. However, these areas are named from **thresholds** (the significant lethal effects, lethal and irreversible thresholds) and not from **intervals**.

In a risk management logic adapted to the environment, we consider it more appropriate to do the counting of the severity in the **discs** than in the crowns for the SEL and the SEI. In short, to estimate the severity associated with an intensity level you must count the people "at least exposed" at this intensity level: a person inside the SELS is particularly exposed to lethal and irreversible effects, and should be counted as such.

Why do we advocate counting in the discs and not in the crowns?

Consider the following pattern:

- No person in the SELS area;
- 11 people in the red crown;
- No one in the orange crown.

If one chooses to count in the crowns, 3 severities are respectively "serious," "catastrophic" and "moderate," i.e., a comprehensive "catastrophic" severity.

Now imagine the movement of a person from the red crown to the purple disk. From a point of view of the individual and societal risk, that situation is worse than the previous: the risk to which a person is exposed is increased without changing the risk level for the other people.

The counting of the severity in the crowns this time gives:

- 1 person in the SELS therefore of "significant" severity;
- 10 people in the red crown therefore of "significant" severity;
- No person in the orange crown therefore of "moderate" severity.

And the overall severity this time is "significant." The severity level of the dangerous phenomena is then reduced, although the situation is worse.

The **counting of the severity in the disks gives:**

In the first case:

- No person in the SELS area;
- 11+0=11 people in the SEL area.
- 0+11+0=11 people in SEI area.

I.e. a "catastrophic" severity.

In the second case:

- 1 person in the SELS area;
- 10+1=11 people in the SEL area;
- 0+10+1=11 people in the SEI area.

I.e. a severity that is also "catastrophic" (because of the SEL area).

The severity level for the dangerous phenomenon, even if it is not increased because of the threshold effects, is not reduced as in the case of the counting in the crowns.

Appendix 5:
Calculation of the Cleared Buildable Surface Area

What is what the buildable surface area?

In the case of a bring to attention, the mastery of urbanization rules are summarized by the following table:

	Probability category A, B, C or D	Probability category E
SELS	Prohibition of any new construction with the exception of industrial plants directly in connection with the business activity at the origin of the risk	Prohibition of any new construction except industrial plants directly in relation to the original activity of the site, developments and extensions of existing facilities or new classified installations subject to licensing compatible with this environment (particularly with regard to domino effects and emergency management situations)
SEL	Prohibition of any new construction except industrial plants directly in relation with the original activity of the site, developments and extensions of existing facilities or new classified installations subject to licensing compatible with this environment (particularly with regard to domino effects and emergency management situations). The construction of transport infrastructure may be authorized only for the functions of serving the industrial zone.	The development or extension of existing constructions are possible. New constructions are possible subject to not increasing the population exposed to these lethal effects. Changes in intended purpose must be regulated within the same framework.
SEI	The development or extension of existing constructions are possible. New constructions are possible subject to not increasing the population exposed to such irreversible effects. Changes in intended purpose must be regulated within the same framework.	Authorization of new construction subject to provisions requiring the construction to be adapted to the overpressure effect when such an effect is generated.
BV	Authorization of new construction subject to provisions requiring the construction to be adapted to the overpressure effect when such an effect is generated.	Authorization of new construction subject to provisions requiring the construction to be adapted to the overpressure effect when such an effect is generated.

It has thus been chosen to consider that in the case of a PAC, the released buildable surface area is the sum of the SELS and SEL surface areas released for the categories A to D scenarios and of the SELS surface areas of the category E scenarios. This corresponds to the shaded boxes in table above.

In the case of a PPRT, the released buildable surface area was taken as equal to the surface area on which land, abandonment or expropriation measures are no longer needed. This surface area is therefore equal to the reduction of F, F+, TF and TF+ areas of the hazards zoning.

Point of vigilance for the PPRT

The hazards give the *a minima* MU rules. The hazards zoning gives a pre-regulation that can be toughened by the State agencies. The previous rule thus gives the theoretical released buildable surface area. It is in practice impossible to calculate exactly, because it depends on decisions made in public meetings by the CSS.

Appendix 6:
Choice of Thresholds for the Costs and Benefits Scales

How were the costs levels allocated?

We have very few examples with already calculated annualized costs, and when they were, they were not associated with decreases in criticality of a major accident. We therefore left the costs in the year 0 (investment costs) that were known, and we allocated an estimated lifespan of the measure of 10 years. With a discount rate of 10%, we deducted the costs intervals.

The idea was to approximately match the cost levels with the following measures:

- level 1: valve, shutoff...
- level 5: setting the bunds, movements (destructions and reconstructions) of several tanks, etc.
- level 4: turning over of an unloading station
- levels 2 and 3: taken linearly between the 2

How were the benefits scales set up?

For now, the setting was done on the basis of the technical-economic studies carried out under the PPRT of La Rochelle and on an Arkema site in the Midi-Pyrénées region.

Comparison with costs of a human life "current risk"

There are cost values of a human life for the risks in everyday life. These costs are estimated by the insurers on the basis of consents to pay and they use them to set insurance premiums. There are numerous public sources on the internet estimating these costs of a human life in France, all giving different values but of the same order of magnitude: between 1 and 3 million Euros.

For accidental risks, this estimated cost is not very relevant: it will be a priori too low because it is more feared to die passively from a technological risk suffered than from an accident in everyday life. We therefore propose, in order to make the comparison, to adopt the higher value for this cost of a human life: 3 million Euros.

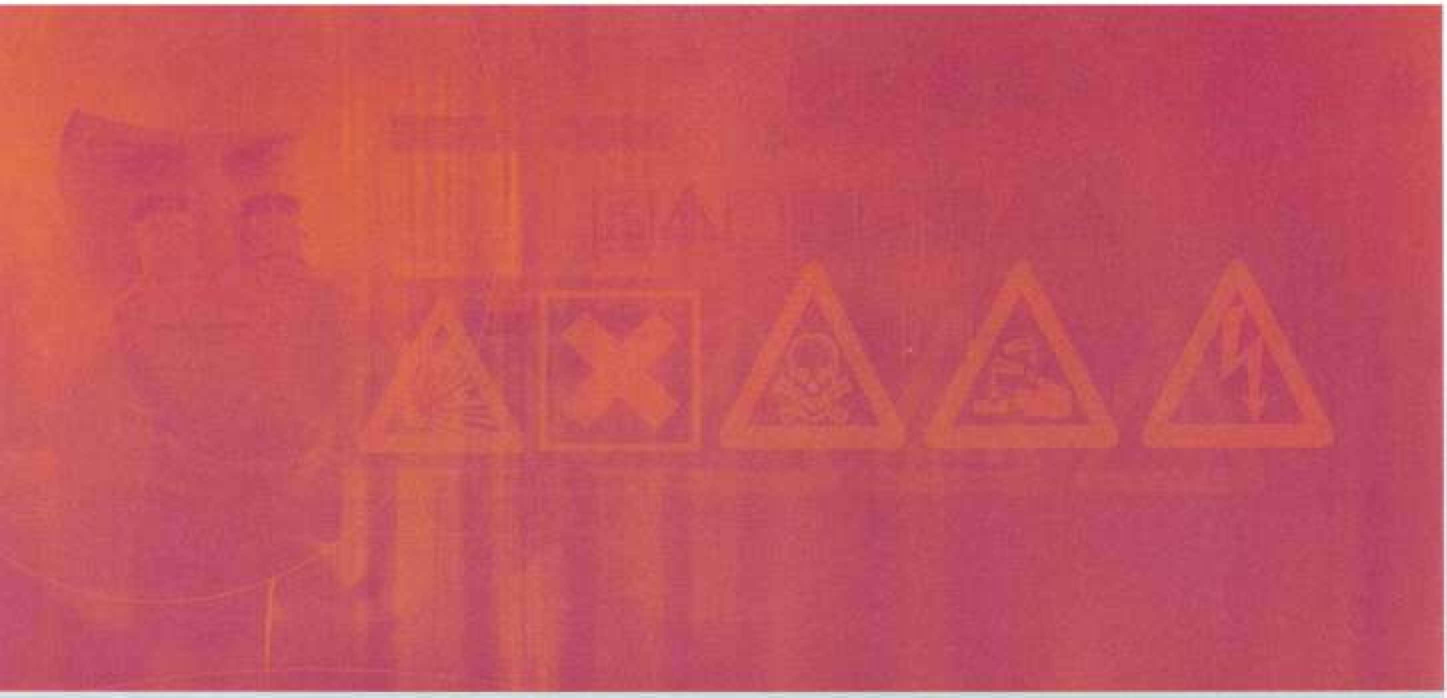
However, it is possible, from these costs of a human life, to convert the cost scale proposed for the measures into a scale of human issues of equal monetary value.

To do this, we must take a default assumption on the probability of occurrence of a category E hazardous phenomenon. We can for example choose the upper bound of the interval, i.e., an annual occurrence probability of 10^{-5}. We should also make assumptions about the average probabilities of death inside the areas of effects, for example 50% in the SEL and 5% in the SELS.

For example, a measure with annualized cost €10,000 is equivalent to $\frac{10000}{3000000} = 0{,}0033$ saved life. For a category E accident and with the previous assumptions, this therefore comes to $\frac{0{,}0033}{0.0033} \sim 667$ people saved from the SEL.

The method presented in this guide recommends however to implement such a measure as soon as at least one person is spared from the SEL, i.e., a factor 667 gap between the two. More generally, if one generalizes this conversion, we get a difference with a factor of 300 to 700.

This confirms that the use of the values of a human life "current risk" are not at all suitable for the case of accidental industrial risk.



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