41st International Petroleum Conference, Bratislava, October 6th-8th, 2003

IMPLEMENTATION OF THE NEW APPROACH OF RISK ANALYSIS IN FRANCE

Jean Claude Couronneau, Amita Tripathi[1]
[1]TRANSOFT International, 7 boulevard de la Libération, 93200 Saint-Denis, FRANCE

ABSTRACT

This paper presents the new approach of risk analysis adopted in summer 2003 by the French Government in the aftermath of the explosion at an industrial site in Toulouse (2001). The implementation of the approach is based on the so-called “Bow Tie” principle: identification of the hazards, circumstances and events leading to the risk as a first fault-tree and, then, the tree of consequences leading from the event to the consequences and the estimated damage area. Events are classified in terms of seriousness and probability, and defence barriers are discussed. Only events of a high seriousness and with a high probability of occurrence will need to be simulated numerically with the help of advanced software.

KEYWORDS

Hazards and Risk Analysis, Probability of Occurrence, Events Classification, Defence Barriers, Quantitative Analyses, Thresholds of Effects

I. Introduction

In the aftermath of the explosion of an industrial site in Toulouse on September 21, 2001 (explosion of a storage of nitrate killing 30 persons), a new law on the technological risks has been adopted by the French government on July 30, 2003. In the same time, a note from the Ministry of Environment (published on June 25 2003) defines more clearly the contents of risk studies.

One of the significant aspects of this law is related to the risk analysis of industrial units which requires investigating all "realistic" scenarios and to estimating the probability of occurrence of the events considered.

II. Implementation of the method

The implementation of this analysis is based on the principle of the “Bow Tie”, principle developed by the SHELL company, to represent the various stages of the risk management in an industrial unit. It starts with the identification of the hazards, describing the various circumstances (or threats) as well as the barriers and domino effects leading to the main event. Thereupon, a certain number of measures of prevention make it possible to attenuate the consequences which eventually will be handled by the crisis management of the facility.

The risk analysis consists of eleven stages described below (Appendix 1).

A. Stage 1 Identification and characterisation of the hazard potential

The hazard identification is the process of finding, listing and characterising the situations, conditions or practices which comprehend in themselves a potential to cause damage to people, goods or environment. These situations, conditions or practices are the hazards.
All potential hazards of installations are identified and characterised without forgetting those related to the modes of supplying and dispatching of goods likely to generate hazards including those by domino effect.
This stage will allow to identify:

- the nature of hazards (possibly by using a checklist),
- the embodiment of these hazards,
- the various circumstances (or threats) likely to generate the hazard,
- the feared events,
- the possible consequences following the events.

This step could be implemented using techniques such as HAZID, HAZOP, APR etc.
A multidisciplinary team uses the checklist to identify the hazards of the installation at all stages of its exploitation. It is the starting point for making of a register of hazard identification.

B. Stage 2 Reduction of hazard potential

For the identified risks likely to have a strong hazard potential, this stage consists in carrying out economic studies aiming at ensuring oneself of the possibility of :

- removing or substituting for processes and dangerous products at the origin of these potential hazards, with processes or products presenting lesser risks,
- reducing as much as possible the quantities of hazardous products.

C. Stage 3 Estimation of potential consequences

This stage consists in an evaluation of the potential consequences of the full release of the hazard present in the system considered, retaining only the physically possible scenarios (for example a BLEVE of an underground tank is not physically possible). In particular the feedback on past accidents in the industrial unit and its specific branch of activity will be taken into account.
The consequences are evaluated in term of seriousness and are classified according to their effects (thermal, mechanical, toxicity, etc.) supplemented by the known elements of kinetics.

This evaluation of the consequences will be made for the people, the goods and the environment.
At the request of the industrial owner, this evaluation of consequences could also be carried out for the reputation and fame of the company.

D. Stage 4 Preliminary evaluation of risks

In this stage, the potential risk will be compared with given criteria of risks.
For each scenario attached to a hazard, the level of potential risk will be evaluated. For this purpose, a matrix of criticality adapted to the industrial unit considered is used. This matrix, specific to the company, is one of the elements of the ‘high environmental quality’ policy of the company.
For each consequence of the studied scenario, its seriousness and its probability will be evaluated (see in Appendix 2 for an example of a matrix). In this case, seriousness goes from 0 to 5 and probability from A to E, followed by the identification of consequence (p) for the people, (b) for the goods and (e) for the environment (for example, 3C(E)).

Each consequence thus evaluated will be positioned in the diagram.

- **The green zone** corresponds to low risk deemed acceptable, if the qualified staff has been given the proper training and the necessary procedures are set up.
- **The orange zone** corresponds to average risk for which it will be necessary to show that the system of safety management is well in place and that it is well applied and that the risk has been brought back to the lowest level possible, with respect to the financial consequences of its implementation and the cost which would be generated by any further reduction (ALARP principle),
- **The red zone** corresponds to intolerable risk which will require a detailed study of each scenario present in this zone with the objective of making it acceptable.

For each scenario, the register of identification will be supplemented by risk values (see example in Appendix 3)

This approach is based on the experience and the judgement of the multidisciplinary team.

E. Stage 5 Selection of critical systems

At this point of the study, as seen in the preceding stage, each scenario is positioned in the diagram of criticality.
All scenarios with consequences located in the red zone will be regarded as critical and will be the subject of further steps.
As a measure of precaution and considering the uncertainties of this approach, it is advisable to include in the critical scenarios all those located in orange zone A5, B5, C4 and D3 for which an increase of seriousness or probability would place them in the intolerable zone.
All scenarios identified as critical will be indexed in a register of major incidents and be the subject of a follow-up study.

F. Stage 6 Detailed study of reduction of risks

For scenarios identified as critical in the preceding stage, an iterative procedure of risk reduction will be conducted. The detailed study of risk reduction concerns all operating conditions (transient stages included). It requires the use of methods of systems analysis. These methods can also reveal the safety importance of the respect of certain conditions taken as assumptions (response time of the operators, for example) of consideration of common mode failures (situations where an event such as an earthquake, a fire, an error of maintenance etc. will simultaneously affect several systems necessary for the safety of the installation) to allow a correct evaluation of the consequences.

For each threat, it will be necessary to identify all the barriers in place that could prevent the feared event or its consequences from happening.
A barrier consists of all instrumental, mechanical or procedural device making it possible to prevent or reduce the probability of occurrence or to limit the consequences of an event likely to lead to an accident. There are barriers of prevention and barriers of protection.

- **Barriers of prevention** serve to prevent or limit the occurrence of the dreaded event,
  Among these, are measures regarding the design, the detection of flow level, pressure, and temperature, safety procedures etc.

- **Barriers of protection** aim at decreasing the consequences of the dreaded event.
  Among these, are :
  - safety procedures,
  - measures of detection (gas, fire, smoke etc.),
  - measures of abatement (water curtain, spraying etc.),
  - plans of internal or external intervention.

The concept of passive or active barriers is rather often used when talking about risk control. The following definitions are proposed:

- A barrier is **active** if it requires a source of energy or a request (automatic or manual action) to fulfill its function (a safety valve, an alarm etc.).
- A barrier is **passive** if it does not need a source of energy nor a request to fulfill its function (a procedure, a retention dike, a firewall etc.)

The criteria of evaluation of barriers will be measured in terms of effectiveness, reliability and availability, three dominating and indissociable characteristics:

- The effectiveness can be defined as the capacity of an element to correctly carry out the task or the function for which it was selected, when the operating conditions are nominal.

- The reliability corresponds to the ability of an entity to achieve a required function, under given conditions, during a given time interval.
- The availability can be defined as the ability of an entity to achieve a necessary function under given conditions at a given moment or during a given time interval. It is assumed that the necessary means are provided and that this barrier was not destroyed by the feared event before having fulfilled its function.

The availability and reliability of the equipment are often difficult to quantify on the basis of statistical data.
The concepts of effectiveness and reliability are devaluated based on such principles as :

- tested concept,
- positive safety,
- tolerance to the first failure,
- strength to the specific constraints,
- testing ability,
- specific – inspection maintenance.

Concerning the choice of barriers, the concept of cost/efficiency is also considered, not all barriers having the same effectiveness.
One will also identify factors of escalation that influence effectiveness or availability of barriers. Those factors likely to involve a degraded function will be identified and included in the system of safety management.

At this level of the study, one will have to define the list of **Important Elements for Safety** (EIPS) starting from the inventory of all barriers. To be described as Significant For Safety, an element (operation or equipment) must be selected from among the defence barriers intended to prevent the occurrence or to limit the consequences of a feared event likely to lead to a potential major accident.
The effectiveness, the reliability and the availability of each one of these EIPS will be examined with particular care without forgetting the analysis of common modes of failure. To ensured the good management of these EIPS is also a task of the System of Safety management.
The probability of failure of each one of these barriers of prevention or protection will be evaluated during the continuation of the study.

G. Stages 7 and 8 Quantification of effects and calculation of distances to risks

For each identified scenario, the feared effects will be quantified using adapted software (for example, the *fluidyn* family: ASSESS-RISK, PANEPR, PANFIRE, PANWAVE, EXPLODE; or PLUME).

a. Physical phenomena

In general, the selected scenarios of accidents can lead to the following physical phenomena:

- toxicity (pollutant gas release),

- wave of overpressure (UVCE, capacity and tank explosion, BLEVE, BOILOVER etc.)
- heat flux (pool fires, fireballs, solid fires),
- missile effects (capacity and tank explosion, rotating components)

b. Thresholds of effects

Depending on the phenomenon, the characteristics of these effects make it possible to determine the thresholds for lethal effects and irreversible effects. The Lethal Effect Threshold (SEL) corresponds to the value below which one does not observe more than 1% of deaths among the exposed population. The Irreversible Effect Threshold (SEI) corresponds to the value below which one does not observe significant effects for the majority of the individuals.

- **Toxicity:** The threshold of the effects corresponds to the maximum concentration of pollutant in the air, for a given duration. One will retain the SEL as threshold of lethality when it is determined, that is to say the CL1% (concentration causing 1 % of lethality after 30 min of exposure). For the threshold of irreversible effects, one will retain the SEI, when it is given, or SES (Significant Effects) called in the past IDLH.
- **Heat flux :** In the case of heat flux, the concept of exposure time determines the choice of the threshold of effects. For the phenomena with duration **longer than one minute,** such as solid fires and poolfires, one uses the concept of static heat flux. The value of **5 kW/m2** is chosen as SEL for an exposure of the population limited to 60 seconds and as SEI the value of **3 kW/m2** for an exposure of the population limited to 60 seconds. For phenomena of duration **shorter than a minute,** such as Flash Fire, UVCE, BLEVE, boil-over, one uses the concept of amount or thermal load. The administration retains as thresholds of SEL the value of **1000 (kW/m2)** $^{4/3}$ **s** and as threshold of SEI, the value of **600 (kW/m2)** $^{4/3}$ **s.**
- **Overpressure:** In the case of overpressure, the thresholds are given starting from the indirect effects of overpressure. The administration retains as SEL the value of **140 mb** and, as SEI, the value of **50 mb.**
- **Missiles:** No threshold was defined for the missile effect, the distances being calculated at the point of impact on the ground

Summary table of various thresholds

EFFECTS	Distances with Risks	THRESHOLDS OF EFFECTS			
		Toxicity	Heat flux		Overpressure
			Static	Dose	
Lethal effects	**Z1**	**SEL or CL 1%**	**5 kW/m** ^{2}	**1 000 (kW/m2)** $^{4/3}$ **s**	**140 mb**
Irreversible effects	**Z2**	**SEI or SES**	**3 kW/m** ^{2}	**600 (kW/m2)** $^{4/3}$ **s**	**50 mb**
Irreversible effects	**PPI**	**SEI or SES**	**3 kW/m** ^{2}	**600 (kW/m2)** $^{4/3}$ **s**	**50 mb**

H. Stage 9 *Evaluation of level of Seriousness/Probability*

- **Calculation of the seriousness factor**
  Once the distances are calculated, the potential consequences on people, goods and the environment will be evaluated starting from the inventory carried out in these zones in terms of the number of people, both as residents and travelling through, type of urbanization and the presence of environmentally sensitive zones (water, air, soil, biotope etc.)

- **Calculation of the probability factor**
  a) Traditional method:
  For the scenarios considered, the probability of each consequence will be evaluated by using the technique of the fault-tree method for the prevention part, until the feared event, and of the event-tree method for each consequence. The kinetics could also be taken into account, for example, if the duration times before the consequences are known (time of detection, time of release, etc...).
  b) Another method:
  In case of the absence of reliable data on the probabilities of the elementary events, another approach can consist in reasoning on the basis of the number of barriers. To define the number of necessary barriers is a matter of experience and judgment.
  It is obvious that the more significant the risk, the more the barriers will be, but it is not easy to determine this number.
  At the time of definition of the number of barriers it will be necessary to be vigilant to count only the independent barriers. For example, an alarm and an automatism on the same point of measurement means only one barrier. In the same way, a procedure of management of an automatism is only one with this automatism.

An example of a realistic approach to the barriers is given in the table below.

Example of management in number of barriers:

Class of risk	Barriers of prevention by identified threat	Barriers of protection by identified consequence	Management of factors of escalation
Green zone	Minimum a barrier of the procedure type	At least a measure of reduction of the consequences	At least an instruction of operation
Orange zone	Minimum of 2 independent ***barriers*** for each threat leading to the principal event.	Minimum of 2 independent ***barriers*** (1) for each one one of the consequences.	At least a means of control (procedure or automatism)
Red zone	Minimum of 3 independent ***barriers*** for each threat leading to the principal event.	Minimum of 3 independent ***barriers*** (2) for each one one of the consequences.	At least two means of control (procedures and/or automatisms)

1. One of the barriers must detect the principal event and the other decrease the consequences
2. One of the barriers must detect the principal event, another decrease the consequences and the third consists of a plan of intervention.
3. Criteria of evaluation of the barriers according to standard CEI 61508.

I. Stage 10 Acceptability of the risk

In this stage of the study, estimates of the consequences in term of seriousness and probability are available. From these two parameters, the level of risk will be evaluated based on the diagram of acceptability (see Appendix 4)

- **The green zone** corresponds to the risk deemed as tolerable,
- **The orange zone** means that it will be necessary to show that the risk is up to a level as low as reasonably realizable,
- **The red zone** corresponds to the intolerable risk.

Each scenario still positioned in the red zone will have to be the subject of a reduction of the risk by the setting up of complementary barriers until reaching a tolerable level of risk. A risk remaining in the red zone in spite of the installation of additional barriers will not be acceptable and alternative solutions must be sought.

J. Stage 11 Establishment of plans of prevention

From the elements defined above, plans of prevention will be established:

- **Plans of Internal Operation** (**POI**) set up by the owner,

- **Plans of Individual Intervention (PPI)** carried out by the local authorities with provisions to be implemented outside the establishment.
  For each one of the major accidents identified in this study for which the consequences have effects outside the site, the cost of potential material damages to the third parties will be estimated in addition to the probability.

- **Plans of Prevention of Technological Risks (PPRT)** worked out by the local authorities in dialog with the owner. This will be used for the control of the urbanization around the sites at risk.