TECHNOLOGICAL RISK PLANNING AS PART OF ENVIRONMENTAL MANAGEMENT

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Abstract— **Although industries operate under safe conditions, an industrial accident may occur, threatening human life, property or environment.**

In the context of environmental management, the importance of taking into account the risk of major technological accidents is concerned not only with the definition of the extent of it consequences but with the measures taken to mitigate unwanted impacts.

With regard to these objectives, the consequence analysis performed in Bahía Blanca industrial area are shown. Bahía Blanca is a middle-size populated town with one of the most important Argentinean petrochemical sites, where dangerous goods are processed, transported and stored. In particular, this work presents the results of evaluating the effects of about 200 possible accidental scenarios involving toxic and flammable substances releases. Hazard areas defined by means of this analysis have been employed to improve the local emergency plan. Finally, an easily understandable document was elaborated in order to achieve the effective risk communication to the local community.

Keywords— **Technological Risk, Consequence Analysis, Environmental Management**.

I. INTRODUCTION

In the implementation of systematic approaches to environmental management, governments are increasingly adopting formal tools to analyze the potential and actual impacts of industrial activities. The interest is focused on two areas: the long-time effects of continuous emissions and the immediate consequences of sudden accidents. With respect to the last aspect it is important to keep in mind that, although industries operate under safe conditions, a failure capable of harming human life, property or environment, may always occur. A main concern in an industrial zone is to manage these potentially serious accidents, which may exceed the plant battery-limits and damage the surrounding community. The strategy for dealing with the risks of major accidents involves their prevention at source as well as the mitigation of effects arising from the ones that actually happen. The first includes the use of safety devices and control procedures inside the plant whereas the second consists in planning the actions to follow during the emergency.

A crucial aspect in emergency management is having the information needed for decision-making. The preparation of contingency plans for chemical risks involves collecting data about the features of the accident and environmental scenarios and the requirements of human and material resources for tackling the emergency. In this matter, the consequences analysis is certainly a very useful tool to identify and define appropriately the resources needed.

In this context, this paper describes the consequence analysis performed in an industrial area, in order to evaluate the effects of different accidental scenarios and update and improve the local technological emergency response plant. The methodology used is explained and finally, the main conclusions obtained from this experience are discussed.

II. AREA DESCRIPTION

Bahía Blanca is a 350,000 inhabitants city in the south of Buenos Aires province, Argentina. It has a very important deep water harbor, near which one of the greatest Argentinean petrochemical sites is located. The industrial area, where different dangerous goods are processed, transported and stored, includes the following facilities:

- a fertilizer complex where 80,000 ton/year of ammonia and 1,100,000 ton/year of urea are produced,
- a polyvinyl chloride manufacturer with a production of 210,000 ton/year,
- a polyethylene plant with a production of 600,000 ton/year,
- a gas separation plant where 533,000 ton/year of ethane and 600,000 ton/year of LPG are obtained,
- a storage and dispatch plant for normal and refrigerated products, with 68,000 m^3 LPG storage capacity,
- an industrial liquefied gases supplier plant with a storage capacity of 346,000 liters,
- a petroleum refinery with a crude oil processing capacity of 31,200 barrels/day.

Besides the fixed installations, there are a natural gas distribution network to feed the industrial complex and several pipelines carrying hazardous substances to the nearby jetties where they are temporally stored in order to be exported by ship.

III.TECHNOLOGICAL RISK PLANNING

To deal with technological risk, Bahía Blanca authorities have put into practice the APELL methodology.

APELL (Awareness and Preparedness for Emergency at Local Level) is a program developed by UNEP in conjunction with governments and industry with the purpose of minimizing the occurrence and harmful effects of technological accidents and environmental emergencies. The strategy of the APELL approach is to identify and create awareness of risks in an industrialized community, to initiate measures for risk reduction and mitigation, and to develop co-ordinate preparedness between industry, local authorities and local population. In Bahía Blanca the APELL program has been applied since 1996 with the participation of the petrochemical industries, the municipal government and the local residents. Work is organized in commissions, such as Evaluation and Risk Analysis, Awareness and Diffusion, Emergency Response and Press and Finances.

The Evaluation and Risk Analysis Commission, formed by industry and academy representatives, was in charge of the development of the consequence analysis and the Civil Protect Department carried out the Bahía Blanca Technological Emergency Response Plan (PRET).

IV. CONSEQUENCE ANALYSIS

Consequence analysis is used to determine the potential for damage or injury from specific incidents, for example the rupture of a pressurized flammable liquid tank, which can have many distinct incident outcomes (jet fire, BLEVE, unconfined vapor cloud explosion). The initiating events are analyzed using source, dispersion, fire and explosion models and effects models are then applied to define the consequences to people, structures or environment.

The analysis performed at the Bahía Blanca Petrochemical Site involved the following steps:

- Hazard identification
- Scenario definition
- Incident outcomes enumeration
- Exposure criteria definition
- Consequence estimation

A. Hazard Zones Definition

Major hazards were identified from an inventory study of hazardous materials in each industry in the Site that included material in storage, in fixed installations and in transport (by truck, train, ship and ducts).

Since in Argentina there are no laws that rule the technical studies that industries should perform associated with the amounts of hazardous materials they manipulate, international regulations were consulted so as to establish which substances and in what amount were considered hazardous and require further analysis. The criteria presented by the Seveso II Directive (European Union, 1996) were selected as a frame of reference for the study. This directive defines two categories of substances: the Name Substances (chlorine, ammonium nitrate, methanol, liquefied extremely flammable gases, etc) and other substances not specially named and classified according to a category of danger (toxic, very toxic, explosive, flammable, very flammable, etc). In both cases the document defines the minimum amount of each substance or kind of substance that is considered hazardous.

As a first step in the hazardous substance inventory, industries informed about the substances they manipulated and in what quantities. Then, these substances were classified according to the Seveso II Directive as is shown in Table 1.

Comparing these data with the amount of substances reported, the most hazardous inventories of the site were found.

Table 1. Classification of hazardous materials according to the Seveso II Directive

Substance	Category of substance according to Seveso II Directive	Minimum hazardous quantity (ton)
Ammonia	Toxic	50
Butane	Named substance	50
Chlorine	Named substance	10
Ethane	Extremely flammable	10
Ethylene	Extremely flammable	10
Hydrogen Chloride	Named substance	25
Natural Gas	Named Substance	50
Propane	Named substance	50
Vinyl chloride	Named substance	50

B. Scenario Definition

The identification of a number of potential events was based on a qualitative analysis of the hazards of the installations. This step considers the detection of all the potential sources of spills or emission for each installation and the selection of top events (accidental events) which can result in different types of emergency situations (scenarios).

Scenario definition includes:

- description of storage or transport conditions (type and dimensions of tanks or vessels, temperature and pressure of storage, pipe connections, etc.),
- selection of rupture sizes
- selection of meteorological conditions and some characteristics of the terrain surrounding.

Sometimes the definition includes the enumeration of the emergency systems that would reduce the effects of consequences. As the aim of the study is to improve the local emergency plan, the concept of worst case scenario is employed as suggested by the World Bank (Technica, 1988), then mitigation system are not taken into account. The scenario definition adopted is shown in Table 2.

The mean values of weather conditions were obtained from an atmospheric study performed in a meteorological station situated near the Petrochemical Site. Wind velocities shown in Table 2 are the most frequent in the zone and are associated to stability atmospheric parameters namely, A (strongly unstable), B (moderately unstable), C (slightly unstable), D (neutral) and F (stable). Most probably wind direction is from the north west quadrant.

Table 2. Characteristic of the adopted scenarios

Type of rupture (hole sizes suggested by World Bank)	Total rupture Top connection rupture. Failure size equal 20% and 100 % of pipe diameter Bottom connection rupture. Failure size equal 20% and 100 % of pipe diameter
Atmospheric conditions	Ambient temperature: 20 ^{o}C Ambient pressure: 1 atm. Humidity: 70% Cloudiness: 40 % Wind velocity: 5.5, 10, 20, 30 km/h
Terrain characteristics	Industrial site with surrounding population

C. Incident Outcomes Enumeration

A single initiating event can originate many different incident outcomes depending the properties of the chemical, conditions of the release, surrounding characteristic, etc. Events and incidents outcome considered in this work and the physical resultant effects are listed in Table 3:

Table 3.Events, incidents outcome and physical resultant effects

Event	Physical effect	Incident outcome
Fire	Thermal radiation	Jet fire, immediate and retarded pool fire, fireball
Explosion	Overpressure, projectiles	Unconfined vapor cloud explosion
Toxic dispersion	Toxic dose	Dense and neutral gas dispersion

D. Exposure Criteria Definition

With the aim of planning and systematizing the response actions it is common practice to define Control Zones. These zones are established as a function of the risk associated with them, then levels of harm are defined and distances are calculated where these levels occur. The Technological Emergency Response Plan considers two control zones:

- **Intervention zone:** the consequences of accidents produce a level of harm that justifies the immediate application of protective actions.
- **Alert zone:** the consequences of accidents produce effects that, although perceptible by the population, do not justify the intervention except for critical groups of people (hospitals, schools, child care facilities, old aged housing, etc.).

The World Bank (Technica, 1988) criteria for thermal radiation damage and overpressure values were adopted to determine control zones for fire and explosion effects. In the first case, the radiation flux adopted corresponds to no discomfort for long exposure and pain if duration is longer than 20 s (blistering is unlikely) for alert and intervention zones respectively. For explosion incidents, the limit for the alert zone was assumed as the window glass broken value and the limit for intervention zone was associated to 1% eardrum rupture.

For toxic threshold, an innovative concept for the definition of the possible damage is selected: the dose criteria described by the Acute Exposure Guideline Levels (AEGLs). AEGLs are public emergency response standards for the general public, including sensitive individuals, developed for each of five exposure periods and defined in three levels:

- AEGL 1: The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.
- AEGL 2: The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
- AEGL 3: The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

The Evaluation and Risk Analysis Commission in agreement with the Emergency Response Commission adopted the threshold values shown in Table 4 to delimit the control zones.

Table 4. Definition of planning zones.

Event	Alert Zone	Intervention Zone
Fire	1.6 kw/m^2	4 kw/m^2
Explosion	35 mbar	170 mbar
Toxic dispersion	AEGL 1	AEGL 2

E. Consequence Estimation

Fire and explosion consequences were evaluated by means of a commercial software, SuperChems® V 3.0, Professional edition (D. Little, 1997), which implements rigorous models for fire and explosion events. On the other hand, toxic dispersion consequences were simulated by means of Aloha (EPA, 2000) since this software includes the toxic dose calculation. To adapt Aloha´s tools to the study purposes, an algorithm of calculation was implemented (Carrari et al., 2004) to take into account the concept of variable time exposure introduced by the AEGLs definition.

F. Hazard Zones Representation

Estimated effects zones were plotted on a map. The source of the events was pointed in the physical area in which they could take place, except for the unconfined vapor cloud explosion. In the latter, the sources were located at the point where half the lower flammability limit took place.

With respect to the shape of affected zones, the ones associated with fire and explosion events were drawn as circles because radiation and overpressure propagates equally towards all positions independently of wind velocity and direction. The zones related to toxic dispersion events took the forms of the contours of the cloud corresponding to the selected level of concern, because these events are dependent principally on wind velocity. In case of explosion and toxic dispersion events, the position of the zones are associated with wind direction, so they can happen in any of the direction of the rose of winds. In this work they were plotted in the two most probable wind directions. Figures 1 to 3 show examples of effect zones for fire, explosion and toxic dispersion events.

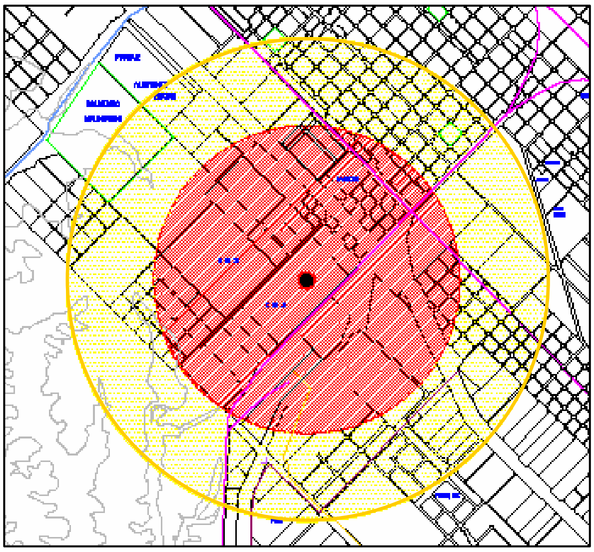


Fig. 1. Hazard zones for thermal radiation
(☐ Alert zone, ■ Intervention Zone)

V. RESULTS

More than 200 scenarios were simulated which include:

- ammonia, ethane, ethylene, butane, propane, hydrogen chloride, vinyl chloride monomer, propylene and nitrogen tanks and spheres
- natural gas and chlorine pipelines
- butane and propane trucks

Consequence analysis was transferred to the Municipal Authorities to be used during the Technological Emergency Response Plan review and update. The whole study was reported both in a printed version and in a user-friendly digital presentation.

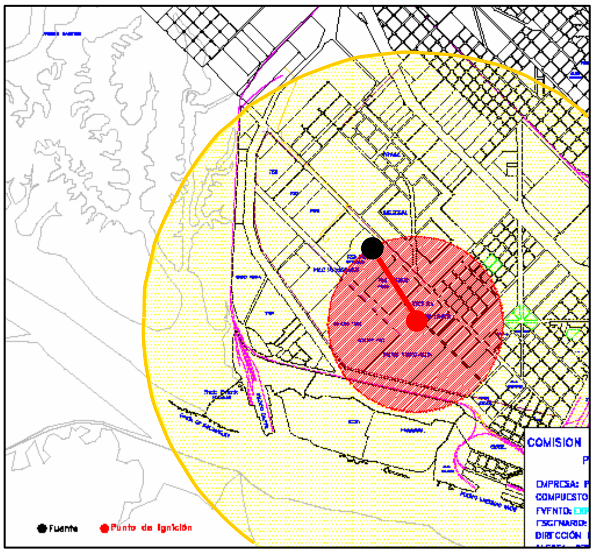


Fig. 2. Hazard zones for overpressure
(☐ Alert zone, ■ Intervention Zone)

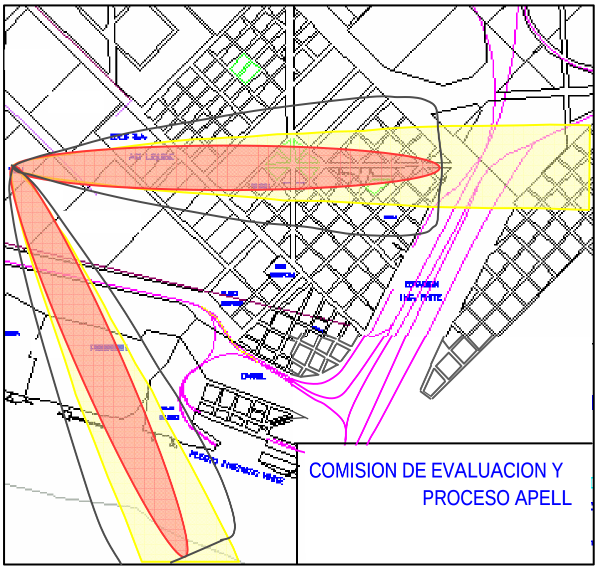


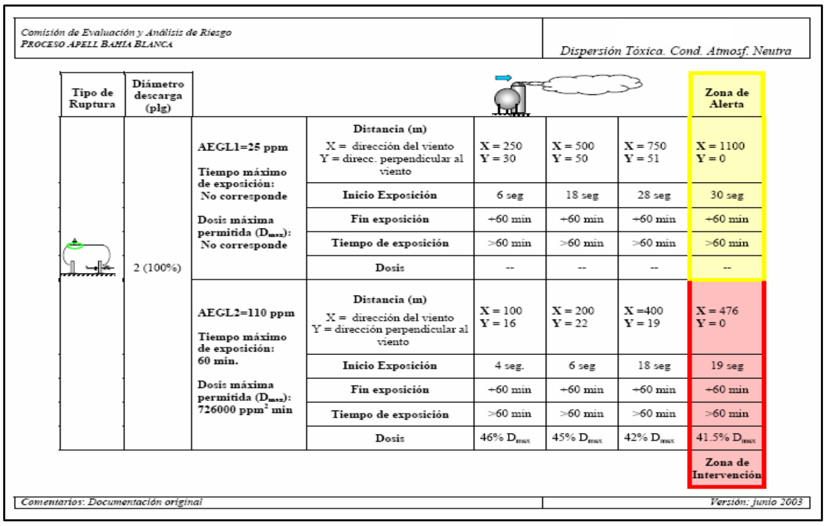
Fig.3 Hazard zones for toxic dispersion
(☐ Alert zone, ■ Intervention Zone)

A. Printed Version

The information was reported in a folder (CAR, 2003) containing a theoretical introduction and the results corresponding to all scenarios in tabulated form as it is shown in Fig. 4, 5 and 6. In all cases, maps showing the Intervention and Alert zone were also included.

B. Digital Presentation

The digital version was presented as a web page with different menus to select among the different scenarios analyzed. Options include plants, substances, outcome events and the corresponding scenario, as it is shown in the example presented in Fig. 7. The results were informed in the same way as in the printed version, including maps plotting the hazard zones.



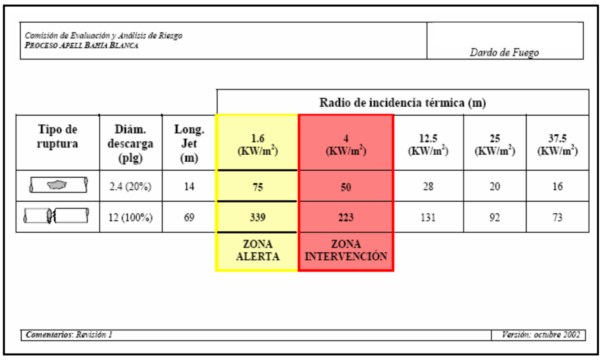
Comisión de Evaluación y Análisis de Riesgo
PROCESO APELL BAHÍA BLANCA

Dispersión Tóxica. Cond. Atmosf. Neutra

Tipo de Ruptura	Diámetro descarga (plg)						Zona de Alerta
	2 (100%)	AEGL1=25 ppm Tiempo máximo de exposición: No corresponde Dosis máxima permitida (D_{max}): No corresponde	Distancia (m) X = dirección del viento Y = direcc. perpendicular al viento	X = 250 Y = 30	X = 500 Y = 50	X = 750 Y = 51	X = 1100 Y = 0
			Inicio Exposición	6 seg	18 seg	28 seg	30 seg
			Fin exposición	+60 min	+60 min	+60 min	+60 min
			Tiempo de exposición	>60 min	>60 min	>60 min	>60 min
			Dosis	--	--	--	--
		AEGL2=110 ppm Tiempo máximo de exposición: 60 min. Dosis máxima permitida (D_{max}): 726000 ppm^2 min	Distancia (m) X = dirección del viento Y = dirección perpendicular al viento	X = 100 Y = 16	X = 200 Y = 22	X =400 Y = 19	X = 476 Y = 0
			Inicio Exposición	4 seg.	6 seg	18 seg	19 seg
			Fin exposición	+60 min	+60 min	+60 min	+60 min
			Tiempo de exposición	>60 min	>60 min	>60 min	>60 min
			Dosis	46% D_{max}	45% D_{max}	42% D_{max}	41.5% D_{max}
							Zona de Intervención

Comentarios: Documentación original — *Versión: junio 2003*

Fig. 4. Consequence analysis for toxic dispersion scenario



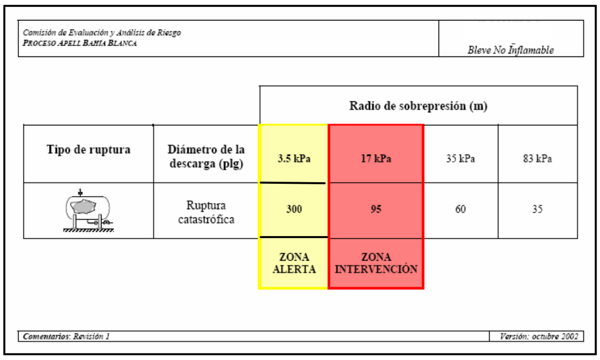
Comisión de Evaluación y Análisis de Riesgo
PROCESO APELL BAHÍA BLANCA

Dardo de Fuego

Tipo de ruptura	Diám. descarga (plg)	Long. Jet (m)	Radio de incidencia térmica (m): 1.6 (KW/m^2)	4 (KW/m^2)	12.5 (KW/m^2)	25 (KW/m^2)	37.5 (KW/m^2)
	2.4 (20%)	14	75	50	28	20	16
	12 (100%)	69	339	223	131	92	73
			ZONA ALERTA	ZONA INTERVENCIÓN			

Comentarios: Revisión 1 — *Versión: octubre 2002*

Fig. 5. Consequence analysis for fire scenarios



Comisión de Evaluación y Análisis de Riesgo
PROCESO APELL BAHÍA BLANCA

Bleve No Inflamable

Tipo de ruptura	Diámetro de la descarga (plg)	Radio de sobrepresión (m): 3.5 kPa	17 kPa	35 kPa	83 kPa
	Ruptura catastrófica	300	95	60	35
		ZONA ALERTA	ZONA INTERVENCIÓN		

Comentarios: Revisión 1 — *Versión: octubre 2002*

Fig. 6. Consequence analysis for explosion scenario

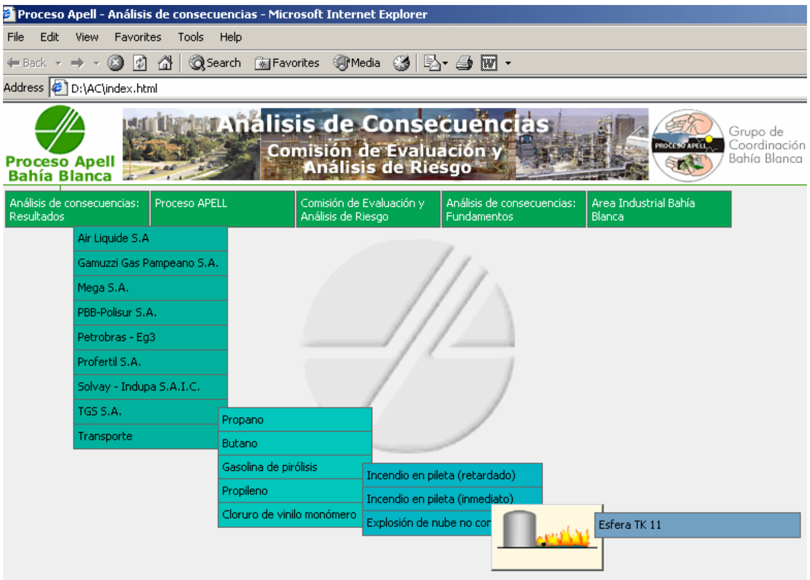


Fig. 7. Screen of the digital version of Consequence Analysis

VI.RISK COMMUNICATION

Hence one of the most important aims in technological risk management is the community awareness about how to deal with risk, an easily understandable document was elaborated in order to achieve the effective risk communication to the local population. The document introduces the concepts of hazard and risk, risk perception and acceptability, accident consequences and probability, emergency response planning and other basic notions concerning these subjects. It is written in non-technical language and complemented with examples from daily life as it shown in Fig. 8.

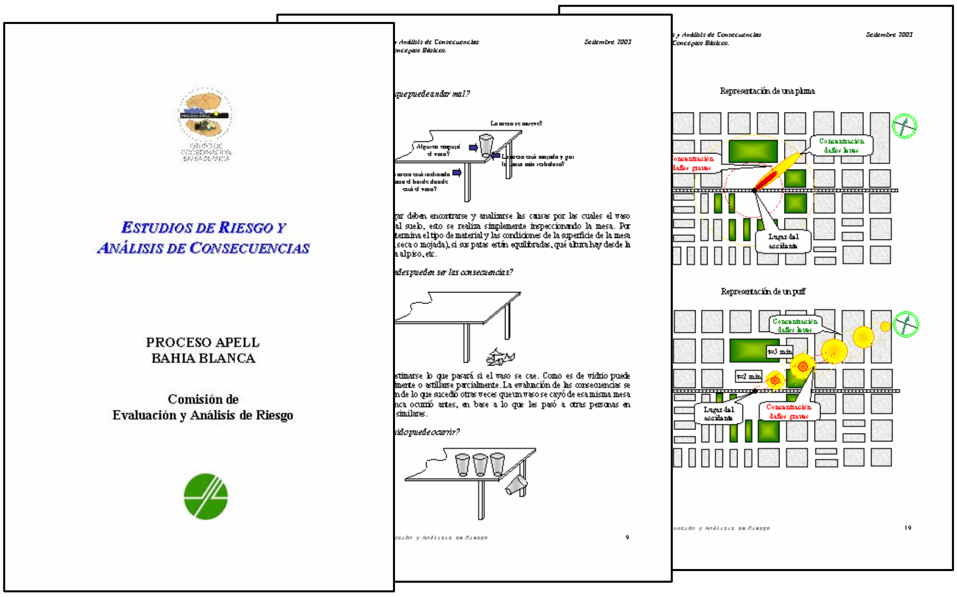


Fig. 8. Risk communication document

VII. CONCLUSIONS

In the context of environmental management, the importance of taking into account the technological accidents is concerned with the definition of the extent of it consequences and with the measures taken to mitigate unwanted impacts.

This work summarized the steps carried out to perform a consequence analysis in an industrial area with the objective of evaluating the effects of different accidents and updating and improving the local technological emergency plan. To do this, an important number of real scenarios were analyzed and its consequences calculated applying rigorous models in order to estimate the possible damage extent in a more accurate form.

Starting from this information, hazard zones were defined to be included in the local Technological Emergency Plan. They have been employed to train response teams and establish vulnerable zones in the community surrounding the Petrochemical site.

In addition to these technical results, it is important to highlight some aspects associated to the social dimension of technological emergencies and the complexity arising from the interaction of technical and organizational factors.

First of all, it should be emphasized the importance of developing and putting to work programs for risk awareness and emergency preparedness like APELL Process. Risk control and prevention is always the best choice.

In relation to the criteria to be used, the lack of national and local specific legislation is a significant drawback since it creates the necessity of consensus, a fact that it is not easy to achieve. In this work, international laws and indexes were adopted to overcome this inconvenient.

Finally, the cooperation within industry and academy during this experience, proved useful for dealing with actual problems of the community associated with technology.

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