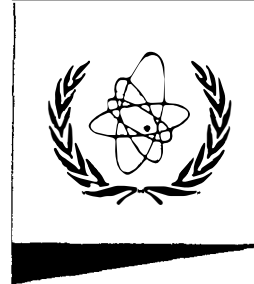




United Nations Environment  
Programme



World Health Organization



International Atomic Energy  
Agency



United Nations Industrial  
Development Organization



Inter-Agency Programme on the Assessment  
and Management of Health and Environmental  
Risks from Energy and Other Complex Industrial Systems

**MANUAL  
FOR THE  
CLASSIFICATION AND PRIORITIZATION OF RISK  
FROM  
MAJOR ACCIDENTS IN  
PROCESS AND RELATED INDUSTRIES**

**DRAFT**

November 1991



INTERNATIONAL ATOMIC ENERGY AGENCY

## **PREFACE**

The Inter-Agency Programme on the Assessment and Management of health and Environmental Risks from Energy and Other Complex Industrial Systems aims at promoting and facilitating the implementation of integrated risk assessment and management for large industrial areas. This initiative includes the compilation of procedures and methods for environmental and public health risk assessment, and the transfer of knowledge and experience amongst countries in the application of these procedures and in the implementation of an integrated approach to risk management.

The programme is being jointly undertaken by four UN organizations: United Nations Environment Programme (UNEP) within the framework of the Awareness and Preparedness for Emergencies at Local Level (APELL); World Health Organization (WHO); International Atomic Energy Agency (IAEA); and United Nations Industrial Development Organization (UNIDO).

The UN organizations sponsoring this programme have been involved for several years in activities that aim at environmental and health risk assessment and management, prevention of major accidents and emergency preparedness. Based on experience from these activities, this manual has been developed by international experts to assist the classification and prioritization of risks in large industrial areas, so that detailed assessment can be undertaken on a priority basis. This is consistent with the need to optimize the allocation of resources in the risk assessment and management processes.

The manual is being distributed in draft on a limited scale at this stage for comments and validation of its proposed methodologies. All comments will be considered prior to finalization of the document. The final document will form part of a 'Procedural Guide for Integrated Health and Environmental Risk Assessment and Safety Management in Large Industrial Areas' being prepared by the Inter-Agency Organizations.

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- International Atomic Energy Agency  
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- United Nations Industrial Development Organization - Vienna
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## 1. INTRODUCTION

### 1.1 Overview

There is a growing need, worldwide, both in developed and developing economies, to ensure that risks to people, properties and the environment from the siting and operations of potentially hazardous and polluting industries and associated activities, are properly assessed and managed. The integration of safety and development concerns to the social and economic benefits of the community are high on the agenda of most countries. Equally, there is an increasing need to ensure efficient and optimum allocation of limited resources in the risk assessment and management processes. To this end, the classification and prioritization of different risks for further detailed assessment is becoming an issue of pressing importance.

The main **aim** of the Manual is to present an overall method and associated procedures for the setting of priorities amongst different sources of risk in order to focus the detailed assessment on a risk priority basis.

### 1.2 Scope of the Manual

- (a) The methods and procedures outlined in the Manual apply to the risks of major accidents with off-site consequences from **fixed installations** handling, storing, and processing hazardous materials; and, **transport** of hazardous materials by road, rail, pipelines and inland waterways. The types of risk being considered are risk of fires, explosions and releases of toxic substances to the public outside the boundaries of hazardous installations. The risk to workers (occupational risk) is not included. The risks of accidents to the natural environment are also not included.
- (b) In interpreting the content of the Manual, **'risk'** is defined in terms of both the consequences and probabilities (likelihood) of unwanted outcomes (hazardous events). **Individual risk of fatality** is defined as the chance (likelihood or probability) per year that anyone member of the general public will be killed as the result of exposure to an activity. **Societal risk** is defined as the relation between the number of people killed in a single accident and the chance or likelihood that this number will be exceeded. The classification scheme indicated in the Manual relates to the societal risk concept.
- (c) The assumptions used in estimating the consequences of accidents indicated in the Manual are such that maximum consequences might be larger than those depicted. Consequence estimations are also based on effects where (without mitigation factors) 100% fatality to the people exposed would occur.

### 1.3 Areas of Application

Large industrial areas accommodate an extensive number of risk sources and activities of varying nature and extent. Such sources may include operating process plants, storage terminals, transportation activities, etc. The same applies at the individual plant level where a number of sources of risk of varying magnitude exist.

Ideally, a cumulative assessment of such risks should include a detailed hazard analysis and quantified risk assessment for all industrial facilities and associated activities. In many cases, however, because of limited resources and time constraints, a preliminary evaluation of the various risks is needed, in order to establish which activities should be the focus of detailed risk assessment in priority to others and where assessment resources should be allocated for the highest return on efforts.

- **The methods and results indicated in the Manual can be used:**
  - (i) To provide a preliminary generalized quantitative overview of the different risks in a large industrial area, based on the concept of societal risk.
  - (ii) To enable the setting of priorities of the different sources of risk for further detailed analysis.

The methods and results indicated in the Manual can only be applied on a relative basis. The absolute values of risk should not be used in isolation.

- **The methods and results indicated in the Manual should not be used:**
  - (a) For the risk assessment of individual facilities, or as a basis for risk management;
  - (b) For decision making on siting hazardous installations or planning routes for hazardous materials transportation;
  - (c) For making any judgement on the safety of any particular installation or activity or on its risk acceptability;
  - (d) For comparing the absolute values with any criteria or standard of risk acceptability.



## 2. OUTLINE OF THE METHOD AND PROCEDURAL STEPS

The method is based on the classification of hazardous activities in the area of interest by way of categorizing consequences and probabilities of occurrence of major accidents. The categorization of consequences lead the user to approximately calculate the number of fatalities caused by an accident in a fixed installation or in the transportation of hazardous materials. The estimations of probabilities yield information on the frequency of accidents (number of occurrences per activity per year). The results can be presented in a graphical form on a x-y system of coordinates where the x-axis shows the classes of consequences and the y-axis the probability classes. Therefore, all hazardous activities in the area can be classified and shown on a matrix format. Once a criterion or several criteria for the acceptability of societal risk have been established, the user can identify on the matrix all the activities which do not satisfy the requirements. The result of the task is a list of activities whose risks have to be further analyzed in more detail in priority to other activities.

A set of assumptions have been made in order to determine the effect categories and the user must be aware of them:

- The intensity of the source is the maximum possible.
- To perform the background calculations for the dispersion of toxic gases, it has been chosen the weather stability class D with wind velocity 5 m/s. It has to be stressed that this is not the worse situation, but it is just an assumption considering an average weather condition.
- Fatality criterion for fires: 100 % fatalities amongst the persons exposed to a heat flux  $\geq 7 \text{ kW/m}^2$  for 30 s.
- Fatality criteria for explosions: for a vapour cloud explosion, 100 % fatalities amongst the persons engulfed in the volume of the burning cloud; LFL ignition criterion assumed (i.e., ignition occurs for vapour concentration  $\geq$  Lower Flammability Limit);  
for explosives, 100 % fatalities for overpressures  $\geq 0.3 \text{ bar}$  (approximately), and for the flying fragments.
- Fatality criterion for toxic clouds: 100 % fatalities amongst the persons exposed for more than 30 minutes to a concentration  $\geq \text{LC}_{50}$  for humans.

Table 2.1 shows the main tasks to be undertaken and their corresponding sections in the Manual.

**Table 2.1. Overview of the main tasks for risk classification and prioritization scheme.**

Tasks	Section in Manual
<b>Classification of Type of Activities and Inventories</b>	3
<b>Estimation of Consequences</b>	4
<b>Estimation of Probabilities :</b>	
<b>Fixed installations</b>	5
<b>Transportation</b>	6
<b>Estimation of Societal Risk</b>	7
<b>Prioritization of Risks</b>	8

A summary description of the procedural steps is provided hereafter.

- **Classification of type of activities and inventories:**

Once the boundaries and the main general characteristics of the area have been identified, generic information has to be collected for all the hazardous fixed installations and all the routes and methods of transportation of hazardous substances (hereafter termed together hazardous activities). Of these activities, only those presenting risks to the public should be selected and more detailed information must be obtained. The handled hazardous substances should then be inventoried and classified.

- **Estimation of external consequences of major accidents to people:**

The method is based on estimating the consequences (i.e., the number of external fatalities), that may be caused by major accidents for each of the activities under

analysis, by multiplying the affected area by the population density within the area and applying a number of correction factors. These factors reflect: the distance to the nearest population; the distribution of population in the area; and, possible mitigating actions.

- **Estimation of probabilities of major accidents:**

- ■ **Fixed installations:**

The method is based on estimating the frequency of major accidents for each of the activities under analysis, by deriving an average (standard) probability number (which is the absolute value of the logarithm of the yearly frequency of occurrence of the accident in that 'standard' activity), and adding to it few probability number correction parameters. These parameters account for: the frequency of loading/unloading operations; the safety systems associated with flammable substances; organizational and safety management; and, the probability of wind direction towards populated areas in the affected zone.

- ■ **Transportation of hazardous material:**

The method is based on selecting an average (standard) probability number for each hazardous substance (or group of substances) identified for each portion of road/railway/waterway/pipeline under analysis, and the application to this standard probability number of few correction parameters. These parameters reflect: the safety conditions of the transport system; the traffic density; and, the probability of wind direction towards populated areas in the affected zone.

- **Estimation of societal risk:**

Each activity is classified according to a scale of consequence classes and a scale of probability classes. All the categorized hazardous activities in the area are thus collected and shown in one matrix of probability vs. consequence.

- **Prioritization of risks:**

The criterion (or criteria) for the acceptability of societal risk must be defined before the task is performed. They can be represented on the matrix so that all the activities which do not meet the requirements can be easily recognized. Activities which do not meet a criterion (or criteria) are selected for further detailed analysis in priority to those activities which meet the criterion (or criteria).

### 3. CLASSIFICATION OF TYPE OF ACTIVITIES AND INVENTORIES

The Manual gives the user the tools to identify and categorize, by means of **Tables**, hazardous activities and hazardous substances. **Appendix 1** shows a useful list of hazardous substances. Throughout the document, the substances are identified by a reference number.

#### Procedural steps:

- Define the boundaries of the area; describe the area. Maps of different scales are essential.
  
- Collect information on all the hazardous activities in the area divided into fixed installations and transportation: name, location, type, production, storage conditions; name, physical state and amount of hazardous substances.

The identification of hazardous substances used in the process includes the estimation of the possibility of formation of secondary hazardous substances by means of chemical reactions or physical processes.

- Classify the activities under different types, using the checklist shown in **Tab. 3.1**.
  
- Exclude from the classification scheme the hazardous activities which do not present direct harm to the public because of the distance to populated areas – the criterion of selection for both fixed installations and transportation is shown in **Tab. 3.2 (a)**.
  
- Exclude from the study the routes with infrequent transport of hazardous substances – the criterion of traffic density is shown **Tab. 3.2 (b)**.
  
- In the case of inland waterways, neglect the transport of soluble liquids and the transport of substances with specific mass greater than 1 kg/dm<sup>3</sup> (density greater than water density).

- Selected roads/railways/waterways/pipelines have to be divided into portions of 1 km. The portions which do not meet the criterion of separation distance to populated areas in **Tab. 3.2 (a)** can be neglected. Within each portion, select the place that is the closest to populated areas. For rail, a particular attention has to be paid to shunting yards.
  
- Consider the inventory of hazardous substances and the lay-out of the facility. Estimate conservatively the maximum amount that could be realistically involved in an accident.

If a facility has physical and very efficient separation amongst the storage vessels of a hazardous substance, the amount to be considered for the estimations is the content of the biggest tank (the other tanks do not participate to strengthen the source term). For physical separation is meant a sufficient distance between storage vessels. For efficient separation is meant the existence of separate tank pits (bunds) or the existence of automatic safety valves in pipelines connecting vessels. Open connections between vessels, or connections with hand-operated valves cannot be considered good physical/efficient separations.

**Table 3.1. Checklist**

Activity		Most important substances	Reference numbers (Table 4.1)
<b>Fuel storage</b>	delivery station	petrol	6
	car station	petrol and LPG	7
	intermediate depot	petrol LPG	6 7, 9
	main storage	oil	1, 3
		petrol	4, 6
		LPG	7, 9, 10, 11
gas cylinder storage	natural gas various gases	10, 11 13	
<b>Processing and storage of fuel</b>	refinery	LPG propane	7
	alkylation process	hydrogen fluoride	31
<b>Transport of fuel</b>	pipeline	LPG, propane	8
		natural gas	12
		petrol	5
		oil	2
	water (inland waterways)	LPG (by pressure)	9
		LPG (by cooling)	11
		petrol	6
		oil	3
rail/road	LPG	7	
	petrol	6	
	oil	4	
<b>Extensive cooling installations</b>	abattoir, dairy, brewery; margarine, ice cream, chocolate industries	ammonia	31
		ammonia	31
	storage of meat, fish, fruit, flowers	ammonia	31
	ice rink	ammonia	31
<b>Food and stimulants</b>	sugar industry	sulphur dioxide	31
	flour industry	methyl bromide	32
	extraction of oils, fats	hexane	1, 3
	yeast factory, spirit		
	distillery	flammable liquids	4, 6
	cocoa industry	hexane	1, 3

**Table 3.1. Checklist (continued)**

	Activity	Most important substances	Reference numbers (Table 4.1)
<b>Specific basic products</b>	leather industry wood industry paper industry	acroleine acids formaldehyde ethylene oxide	18, 21 32 30
	rubber industry	epichlorohydrine styrene acrylonitril	16, 17 4, 6 18, 21
<b>Metallurgical, electronic industries</b>	blast furnaces	carbon monoxide	31
	surface treatment	ammonia arsine	31 34
<b>Specific chemicals</b>	fertilizers	ammonia combustion products	31, 36 43
	sulphuric acid	sulphur oxides	45
	synthetic resins	ethylene oxides	30
		chlorine	32
		acrylonitrile	18, 21
		phosgene	33
		formaldehyde	32
	plastics/synthetics	vinylchloride	7
		acrylonitrile	18, 21
		chlorine	32
	paints/pigments	combustion products	46
		phosphine	33
		solvents	4, 6
chlorofluorocarbons (CFCs)	combustion products	46	
	hydrogen chloride	40, 42	
	chlorine	32	
	hydrogen fluoride	31	
chlorine	chlorine	32, 37	
vinylchloride	chlorine	32	
	vinylchloride	7	
	hydrogen chloride	40, 42	
ammonia	ammonia	31, 36	
hydrogen chloride	hydrogen chloride	40, 42	
	chlorine	32	
fibers	carbon disulphide	18	
	hydrogen sulphide	32	
drugs/pharmaceuticals	chlorine	32	
	solvents	4, 6	

**Table 3.1. Checklist (continued)**

Activity		Most important substances	Reference numbers (Table 4.1)		
<b>Pesticides</b>	raw material production	phosgene	33		
		isocyanates	26, 29		
		chlorine	32		
		combustion products	43		
	formulation and storage	combustion products	43		
	retail and storage	combustion products	43		
		methylbromide	32		
<b>Explosives</b>	production and storage	various	14		
	storage of ammunitions	various	14, 15		
<b>Public places and utilities</b>	waterworks	chlorine	32		
	storage of pesticides	combustion products	43		
<b>Harbour facilities</b>	containers	various	<sup>a</sup>		
	tanks (storage facilities)	various	<sup>a</sup>		
<b>Transport</b>	pipelines	chlorine	41		
		ammonia	40		
		ethylene oxide	40		
		hydrogen chloride	41, 42		
	road and rail (also shunting yards)	flammable gases <sup>b</sup> :	23, 236, 239	7	
		flammable liquids <sup>b</sup> :	33, 336, 338		
			339, 333, x338		
			x323, x423, 446		
			539	6	
			toxic gases high <sup>b</sup> :	26, 265, 266	32
			toxic gases medium <sup>b</sup> :	236, 268, 286	31
			toxic liquids <sup>b</sup> :	336, 66, 663	19
			explosives <sup>b</sup> :	1.1, 1.5	14
			flammable gases <sup>b</sup> :	23, 236, 239	9 <sup>c</sup> , 11 <sup>d</sup>
water	flammable liquids <sup>b</sup> :	33, 336, 338			
		339, 333, x338			
		x323, x423, 446			
		539	6		
		toxic gases high <sup>b</sup> :	26, 265, 266	32 <sup>c</sup> , 37 <sup>d</sup>	
		toxic gases medium <sup>b</sup> :	236, 268, 286	31 <sup>c</sup> , 36 <sup>d</sup>	
	toxic liquids <sup>b,c</sup> :	336, 66, 663	20		

<sup>a</sup> See **Appendix 1** for specific Reference numbers.

<sup>b</sup> International classification codes for transport (also in **Table 6.1**).

<sup>c</sup> Pressurized.

<sup>d</sup> Cooled.

<sup>e</sup> Insoluble; specific weight  $\leq 1$  kg/dm<sup>3</sup>.



**Table 3.2. Criteria for the selection of industrial activities to be included in the study.**

**(a) Criterion of distance from populated areas <sup>a</sup>.**

Industrial activity		Distance from populated areas (m)
Stationary installations	flammable substances and/or explosives	< 500
	specifically:	
	· petrol station	< 50
	· LPG station	< 100
	· pipeline with flammable liquids	< 50
· storage of cylinders (25-100 kg)	< 100	
	toxic substances	< 10000
	specifically:	
	· cooling installation	< 100
	· storage of pesticides for retail	< 50
Transport	LPG, by:	
	rail/road	< 100
	water	< 200
	petrol, by:	
	rail/road	< 50
	water	< 200
	oil, by:	
	rail/road	< 25
water	< 100	
	toxic substances, by:	
rail/road	< 500	
water	< 1000	

<sup>a</sup> The values are related to the maximum possible quantities (and maximum toxicity for toxic substances) that exist in normal industrial practice.

**Table 3.2. Criteria for the selection of industrial activities to be included in the study. (continued)**

**(b) Criterion of traffic density.**

Industrial activity		Traffic density (number of units/yr)	
Transport	gas, by:	road	> 500
		rail	> 5000
		on shunting yards	> 50
		water	> 500
	liquids, by:	road	> 50
		rail	> 5000
		on shunting yards	> 50
		water	> 50
	explosives, by:	road	> 200
		rail	> 5000
		on shunting yards	> 50
		water	> 200

#### 4. ESTIMATION OF CONSEQUENCES OF MAJOR ACCIDENTS TO PEOPLE

Once sufficient information on the hazardous activities in the area have been gathered and structured as indicated in Section 3, the external consequences of major accidents can be calculated for each selected activity.

In the context of the Manual, external consequences of an accident mean the number of fatalities amongst people that are living or working in the area surrounding the facility where the hazardous activity takes place; or, the road/rail/waterway/pipeline where hazardous substances are transported.

The external consequences ( $C_{a,s}$ , number of fatalities/accident) of an accident caused by the substance (subscript s) for each identified activity (subscript a), can be calculated using the **formula (4.1)**:

$$C_{a,s} = A \cdot \delta \cdot f_A \cdot f_m$$

where:

$A$  = affected area (hectares; one hectare is  $10^4 \text{ m}^2$ );

$\delta$  = population density in populated areas within the affected zone (persons/ha);

$f_A$  = area correction factor for the distribution of population in the affected zone;

$f_m$  = correction factor for mitigation effects.

##### Procedural steps:

- Select one of the activities.
  
- If more than one substance in the same activity can cause damage independently from the other substances, analyze them separately. If a group of substances may act together, consider as a single (equivalent) substance. If a flammable substance is also toxic, both effects have to be accounted for.

- Classify the activity using **Tables 4.1.a** and **4.1.b** (the latter relates to substances flowing in pipelines).

The substances are subdivided by:

- the type of potential harm (flammability, explosiveness and toxicity);
- the general physical and chemical characteristics; and,
- the type of activity.

The substances can then be classified according to the quantity involved in the accident (**Tab. 4.1.a**).

In the case of a pipeline, the key parameter for classification is its diameter (**Tab. 4.1.b**).

The definition of the effect categories (or classes) is shown in **Tab. 4.2**. The categorization is by means of two effect categories: the maximum distance of effect (metre) and the affected area (hectare).

**Figures 4.1** and **4.2** illustrate the procedure in two significative cases:

**Figure 4.1** shows an example of circular affected area (effect area category I – typical of explosions);

**Figure 4.2** shows an example of affected area equivalent to a sector of a circle (effect area category III – typical of toxic releases, see **Tabs. 4.1.a** and **4.2**).

- Record the maximum distance of effect (**R** in the figures) and the affected area (**A**) from **Tab. 4.2**.
- Estimate the distribution of population within the circular area whose radius is the maximum distance of effect. Estimate the density of population ( $\delta$ ) in the most important part(s).

If the value is not known or if the time/team resources are not sufficient, an estimation of the population density in populated areas can be made using **Tab. 4.3**, on the basis of the generic description of the area.

As an example, **Figs. 4.1** and **4.2** show two populated areas within the circle whose radius is the maximum distance of effect ( $R$ ). If the affected area is a circle (**Fig. 4.1**, area category I), all the populated areas that are comprised within the circle whose radius is the maximum distance of effect must be included in the estimation. The consequence of the accident is then the total number of fatalities in all the included areas. If the affected area is a sector of circle (i.e., effect area categories II and III – example of category III in **Fig. 4.2**), the user must choose the sector which maximizes the calculated consequences  $C_{a,s}$ .

- Estimate the area correction factor  $f_A$ .

This factor is the fraction of the effect area  $A$  which is populated (i.e., ratio of populated affected area(s) to the effect area). Examples are shown in **Figs. 4.1** and **4.2**.

It could be difficult or require long time to correctly evaluate the fraction – a recent map could not be available or the contours of populated areas could be complicate.

A way to solve the problem is to calculate an approximate area of the populated zones and to divide it by the effect area  $A$ . An approximation of the area can be the smallest portion of a sector of a circle that include the populated area; its calculation can be done in three steps, for each populated area:

- calculate the fraction  $f_r$  ( $\leq 1$ ) of the area of the ring that include the populated zone (within the maximum distance of effect  $R$ ) to the area of the circle whose radius is the maximum distance of effect:

$$f_r = \frac{R_{\max}^2 - R_{\min}^2}{R^2}$$

where  $R_{\max}$  ( $\leq R$ ) is the outer radius (i.e., the maximum distance of the populated zone from the hazardous activity) and  $R_{\min}$  the inner radius (i.e., the minimum distance of the populated zone from the hazardous activity);

- calculate the fraction  $f_\alpha$  ( $\leq 1$ ) of the angle  $\alpha$  which includes the populated zone to the angle  $\theta$  of the affected sector ( $\theta = 360^\circ$  for area category I;  $\theta = 180^\circ$  for area category II;  $\theta \approx 30^\circ$  for area category III):

$$f_\alpha = \alpha/\theta$$

- the area factor  $f_A$  is the product of these sub-factors:

$$f_A = f_r \cdot f_\alpha$$

If even the application of this simplified method for calculating  $f_A$  were not feasible, a rough estimation of the factor can be made by means of **Tab. 4.4**. The table shows  $f_A$  as function of the area category and the populated fraction of the circular area whose radius is the maximum distance of effect.

- Estimate the correction factor  $f_m$  (proposed values in **Tab. 4.5**).

This correction factor accounts for possible mitigation actions that could be taken by people, such as evacuation, sheltering, etc. These actions are highly dependent on the type of the accident and the substance involved.

For example, in the case of explosions, mitigation opportunities are limited and hence no correction applies ( $f_m = 1$ ). An exception is the proposed value for storage of cylinders of flammable gases – reference number 13 – for which  $f_m = 0.1$  owing to the fact that they explode in sequence and not as a whole.

The proposed small values for toxic substances are justified by:

- the time a person should be exposed before a lethal effect occurs;
- the time needed for the dispersion at long distances;
- the warning from odour, etc.

A significant part of the exposed persons could then take effective protective actions like to flee, shelter, etc.

- Calculate the external consequences  $C_{a,s}$  using the **formula (4.1)**.
- Repeat all steps above for all stationary activities and transportation routes.

## 4.1. Example

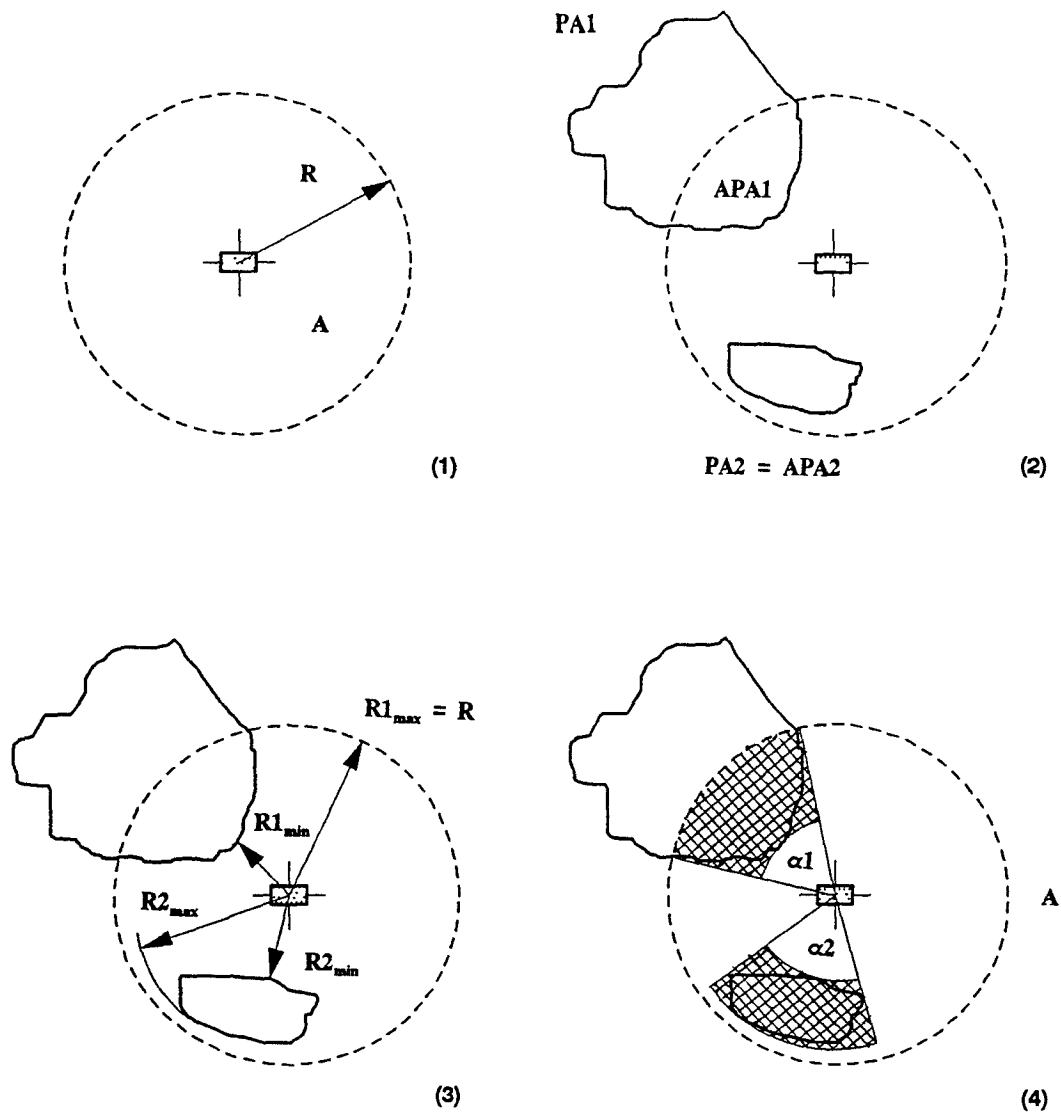
A storage of petrol contains 2000 t. It is provided with tank pit (bund). A village could be affected by a major accidents; its population density is about 20 persons/ha. The minimum distance of the village from the storage is 30 m. The village extends beyond the distance of 100 from the storage. The village occupies 20% of the area within 100 m from the storage.

### Estimation:

- . **Appendix 1, Table 3.1** (Checklist) and **Table 4.1.a:** Storage of petrol with tank pit: Reference number = 4.
- . **Table 4.1.a:** 2000 t: Effect categories = C II.
- . **Table 4.2:** Effect categories C II correspond to: maximum distance of effect = 100 m; and, affected area = 1.5 ha.

We have only rough information on the village; thus, for the estimation of the correction factors we make use of the data in the **Tab. 4.3** and **4.4:**

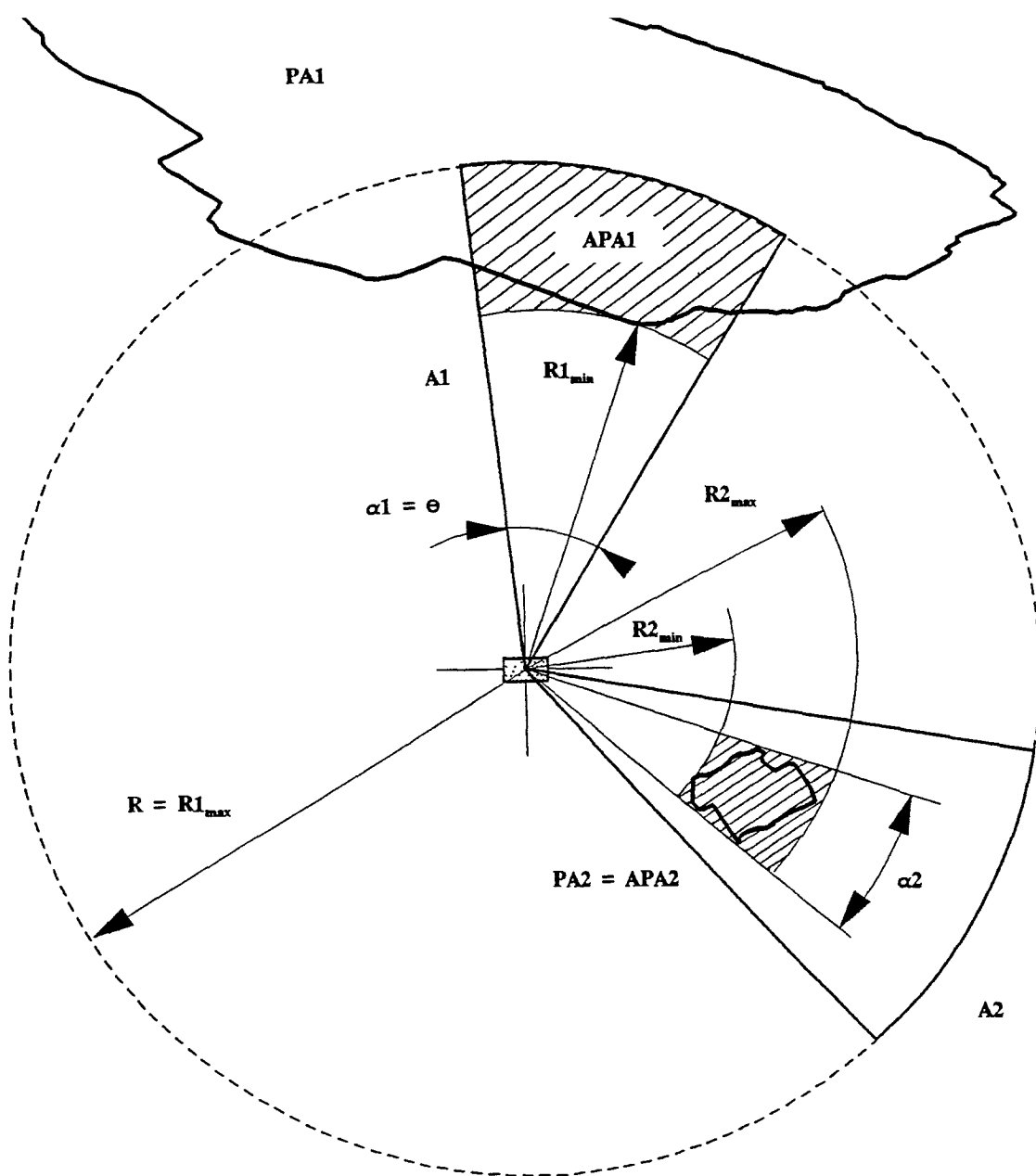
- . **Table 4.3:** Population density in the village = 20 persons/ha.
- . **Table 4.4:** Correction factor for the distribution of population = 0.4 (effect area category II; the part of area where dwellings are located is 20% of the circular area with a radius of 100 m).
- . **Table 4.5:** Correction factor for mitigation = 1 (flammable substance, reference number 4).
- Estimation of the number of fatalities:  
 $1.5 \text{ (ha)} \cdot 20 \text{ (persons/ha)} \cdot 0.4 \cdot 1 = 12 \text{ fatalities.}$



Steps	Description
(1)	Estimation of affected area A and maximum distance of effect R (Tab. 4.2).
(2)	Identification of Populated Areas (PA) and Affected Populated Areas (APA); estimation of population density $\delta$ (Tab. 4.3).
(3)	Estimation of minimum and maximum distances ( $R_{\min}$ and $R_{\max}$ ) of populated areas from the hazardous activity.
(4)	Estimation of the ratio Total APA (or, approximately, the sum of hatched areas) to A (or estimation of $f_A$ from Tab 4.4).

Figure 4.1. Illustration of estimation of consequences for effect area category I.





Symbols	Description
<b>R</b>	Maximum distance of effect (Tab. 4.2).
<b>A</b>	Affected area (Tab. 4.2).
<b>PA</b>	Populated Area.
<b>APA</b>	Affected Populated Area (population density $\delta$ from Tab. 4.3).
<b><math>R_{min}</math></b>	Minimum distance of populated area from the hazardous activity.
<b><math>R_{max}</math></b>	Maximum distance ( $\leq R$ ) of populated area from the hazardous activity.
<b><math>\theta</math></b>	Angle of affected sector.
<b><math>\alpha</math></b>	Angle of sector including affected populated area.

**Figure 4.2.** Illustration of estimation of consequences for effect area category III. The sector which results in the highest number of calculated casualties must be chosen.

**Table 4.1.a Classification of substances by effect categories.**

**Table 4.1.a Classification of substances by effect categories.**

Ref. No.	Type of substance	Description of substance	Activity
1 2 3 4 5 6	Flammable liquid	Vapour pressure < 0.3 bar at 20°C	Storage with tank pit Pipeline Other
		Vapour pressure ≥ 0.3 bar at 20°C	Storage with tank pit Pipeline * Other
7 8 9 10 11 12 13	Flammable gas	Liquified by pressure	Rail, road, overground storage Pipeline * Other
		Liquified by cooling	Storage with tank pit Other
		Under pressure	Pipeline * Storage of cylinders (25-100 kg)
14 15	Explosive	In a bulk (causing single explosion)	
		In packages (e.g. shells)	
16 17 18 19 20 21 22 23 24 25 26 27 28 29	Toxic liquid	Low toxicity	Storage with tank pit Other
		Medium toxicity	Storage with tank pit Road/rail Water Other
		High toxicity	Storage with tank pit Road/rail Water Other
		Very high toxicity	Storage with tank pit Road/rail Water Other
30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46	Toxic gas	Liquified by pressure: low toxicity medium t. high t. very high t. extreme t.	
		Liquified by cooling: low t. medium t. high t. very high t. extreme t.	
		In pipelines *: medium t. high t.	
		Under pressure > 25 bar: high t.	
		Toxic combustion products	From pesticides From fertilizers (with nitrogen) From sulphuric acid From plastics (with chlorine)

Categories for pipelines are shown in part b of the Table.

Table 4.1.a Classification of substances by effect categories (continued)

Ref No.	Quantity (t)						
	5-10	10-50	50-200	200-1000	1000-5000	5000-10000	> 10000
1	-	-	-	A I	B I	B I	C I
2 <sup>a</sup>	-	-	-	-	-	-	-
3	-	A I	B I	C I	D II	X	X
4	-	-	-	B I	C II	C II	D II
5 <sup>a</sup>	-	-	-	-	-	-	-
6	-	B II	C II	D II	E II	X	X
7	B I	C I	D I	E I	X	X	X
8 <sup>a</sup>	-	-	-	-	-	-	-
9	C III	C III	D III	X	X	X	X
10	-	-	-	B I	C II	C II	D II
11	-	B II	C II	D II	E II	X	X
12 <sup>a</sup>	-	-	-	-	-	-	-
13	C III	C II	C I	C I	X	X	X
14	B I	C I	C I	D I	X	X	X
15	C III	C II	C I	D I	X	X	X
16	-	-	-	A II	A II	B II	C III
17	-	A III	A II	B II	C II	C II	C II
18	-	A III	B III	D III	E III	F III	F III
19	C III	D III	X	X	X	X	X
20	D III	E III	F III	X	X	X	X
21	C III	D III	E III	F III	F III	X	X
22	A II	B III	C III	E III	F III	G III	G III
23	D III	E III	X	X	X	X	X
24	E III	F III	G III	X	X	X	X
25	D III	E III	F III	G III	G III	X	X
26	C III	E III	F III	G III	G III	H III	H III
27	E III	F III	X	X	X	X	X
28	F III	G III	H III	X	X	X	X
29	E III	F III	G III	H III	H III	X	X
30	A II	A I	B II	B I	C III	C II	X
31	B II	C II	D III	E III	F III	F III	X
32	E III	E III	F III	F III	G III	X	X
33	F III	G III	G III	G III	X	X	X
34	G III	H III	H III	X	X	X	X
35	A II	A II	A II	B II	B II	B II	X
36	C II	C II	D III	D III	D III	E III	X
37	D III	E III	E III	E III	F III	X	X
38	F III	F III	G III	G III	X	X	X
39	G III	H III	H III	X	X	X	X
40 <sup>a</sup>	-	-	-	-	-	-	-
41 <sup>a</sup>	-	-	-	-	-	-	-
42 <sup>a</sup>	-	-	-	-	-	-	-
43	A II	B II	D III	E III	E III	X	X
44	B II	C III	E III	F III	F III	X	X
45	-	A II	C III	D III	D III	X	X
46	-	A II	C III	D III	D III	X	X

Symbols: X means the combination of that substance and that amount does not exist in practice; - means ignorable effects.

**Table 4.1.b Classification by effect categories of substances flowing in underground pipelines outside plants.**

Ref. No.	Type of substance	Description of substance	Diameter (m)	Category
2	Flammable liquid	Vapour pressure at 20°C < 0.3 bar	> 0.2	A I
5		Vapour pressure at 20°C ≥ 0.3 bar	0.2 - 0.4 > 0.4	A I B II
8	Flammable gas	Liquified by pressure	< 0.1	C I
12			0.1 - 0.2 > 0.2	D I E I
		Under pressure	0.2 - 1 > 1	A I B I
40	Toxic gas	Medium toxicity	< 0.1	E III
			0.1 - 0.2	F III
41		High toxicity	< 0.1 0.1 - 0.2	F III G III
42		Pressure > 25 bar, high toxicity	< 0.02 <sup>a</sup> 0.02 - 0.04 <sup>a</sup> 0.04 - 0.1 <sup>a</sup>	D III E III F III

<sup>a</sup> Diameter of the largest pipe connected.

**Table 4.2. Effect categories: maximum distance and area of effect.**

Effect distance (m) category		Effect area category (ha)*		
		I	II	III
A	0 - 25	0.2	0.1	0.02
B	25 - 50	0.8	0.4	0.1
C	50 - 100	3	1.5	0.3
D	100 - 200	12	6	1
E	200 - 500	80	40	8
F	500 - 1000	—	—	30
G	1000 - 3000	—	—	300
H	3000 - 10000	—	—	1000

\* 1 ha = 10<sup>4</sup> m<sup>2</sup>.

Note:

The capital letters A-H represent the effect distance categories in increasing order; the roman numbers I-III represent the effect area categories in decreasing order.

Each effect distance category is defined by a range of values for the corresponding maximum distance of effect, in metres.

Each effect area category is defined by one value which is the estimated affected area, in hectares. I corresponds to the circular area with the maximum distance of effect as diameter; II to the area of the semicircle; and, III to about 1/10 of the area of the circle. A distance category can be found in combination with each of the area category. The exception of F, G and H, which combine only with the area category III, can be explained by the fact they are related to the dispersion of large amounts of toxic gases in elongate clouds.

**Table 4.3. Population density ( $\delta$ ).**

Description of the area	Density (persons/ha)
Farmland, scattered houses	5
Individual dwellings	10
Village, quiet residential area	20
Residential area	40
Busy residential area	80
Urban area, shopping centers, centre of city	160

**Table 4.4. Correction factor ( $f_A$ ) for the distribution of main populated area(s) into the circle whose radius is the maximum distance of effect.**

Effect area category	Populated fraction (%) of the circular area				
	100%	50%	20%	10%	5%
I	1	0.5	0.2	0.1	0.05
II	1	1	0.4	0.2	0.1
III	1	1	1	1	1

**Table 4.5. Correction factor ( $f_m$ ) for mitigation.**

Substances (Reference numbers)		Factor
Flammables	(1 - 12)	1
Flammables	(13)	0.1
Explosives	(14, 15)	1
Toxic liquid	(16 - 29, 43 - 46)	0.05
Toxic gas	(30 - 34, 40 - 42)	0.1
Toxic gas	(35 - 39)	0.05



## 5. ESTIMATION OF PROBABILITIES OF MAJOR ACCIDENTS FOR FIXED INSTALLATIONS

To calculate the frequency ( $P_{i,s}$ , number of accidents/year) of accidents involving a hazardous substance (subscript s) for each hazardous fixed installation (subscript i), which causes the consequences that have been estimated in Section 4, it is necessary to calculate the related so-called probability number ( $N_{i,s}$ ).

$N_{i,s}$  can be calculated using the **formula (5.1)**:

$$N_{i,s} = N_{i,s}^* + n_l + n_f + n_o + n_p$$

where:

- $N_{i,s}^*$  = the average probability number for the installation and the substance;
- $n_l$  = probability number correction parameter for the frequency of loading/unloading operations;
- $n_f$  = probability number correction parameter for the safety systems associated with flammable substances;
- $n_o$  = probability number correction parameter for the organizational and management safety;
- $n_p$  = probability number correction parameter for wind direction towards the populated area.

The probability number can then be converted into a probability, either using **Tab. 5.6** or directly, from the relationship between N and P:

$$N = |\log_{10} P|$$

### Procedural steps:

- Select one of the activities.

- If more than one substance can cause damage independently from the other substances, analyze them separately. If a group of substance may act together, consider as a single (equivalent) substance.
- Select the average probability number for each hazardous substance (or group of substances) identified for each of the activities (**Tab. 5.1**).

- Estimate the probability number correction parameter  $n_l$  (**Tab. 5.2**).

This parameter accounts for the frequency of loading/unloading operations of the hazardous substances at the plant.

- Estimate the probability number correction parameter  $n_f$  (**Tab. 5.3**).

This parameter is to be used only for flammable substances. It takes into account the presence of safety systems and the number of stored cylinders.

- Estimate the probability number correction parameter  $n_o$  (**Tab. 5.4**).

This parameter accounts for organizational and safety management aspects, such as: the age of the facility, the quality of safety management, the existence and quality of safety procedures, the quality and practice of maintenance, the existence of emergency and evacuation plans, etc. Care should be very taken in estimating the parameter, especially if the facility cannot be directly surveyed.

- Estimate the probability number correction parameter  $n_p$  (**Tab. 5.5**).

This parameter takes into account the probability of wind direction towards the populated area(s) that have been previously identified to be the most important in the circle whose radius is the maximum distance of effect.

In particular, the parameter does not apply for accidents causing symmetric effects (i.e. with circular affected area, effect area category I; typical of explosions).

In the case of partialized affected area (effect area categories II and III; typical of dispersion of toxic substances), the user must consider the same sector of circle that has been considered following the instruction given in Section 4 for the correction factor  $f_p$ .

If the affected area is partialized, but the population lives all around the activity, the parameter is zero.

The values shown in **Tab. 5.5** are calculated assuming a uniform distribution of the frequencies of wind directions in the wind rose.

- Calculate the probability number  $N_{i,s}$  using the **formula (5.1)**.
  
- Convert the probability number into probability  $P_{i,s}$  by means of **Tab. 5.6** or directly, using the definition of N.
  
- Repeat all steps above for all stationary activities.

## 5.1. Example

A storage of 1700 cylinders of 40 kg of weight containing propane and butane is provided with a fire protection wall and a sprinkler system. The minimum distance between the storage and a populated area is 10 m. The populated area occupies about 15% of the circular area between 10 m and 100 m from the storage.

### Estimation

- . **Appendix 1, Table 3.1** (Checklist) and **Table 4.1.a**: Storage of flammable gas: Reference number = 13.
  - . **Table 4.1.a, Table 4.2**: Total mass of gas =  $0.04 \cdot 1700 = 68$  t; effect category = C I (effect distance = 100 m; effect area = 3 ha).
  - . **Table 5.1**: Standard probability number = 4.
  - . **Table 5.2** to be skipped (see note).
  - . **Table 5.3**: Three probability number correction parameters for flammable have to be considered:
    - fire protection wall = + 1
    - sprinkler system = + 0.5
    - more than 500 stored cylinders = - 1
- Total correction parameter for flammable = + 0.5
- . **Table 5.4**: Probability number correction parameter for management, etc.: we assume that for the activity under analysis = - 0.5.
  - . **Table 5.5**: Probability number correction parameter for the distribution of population within the circular area and the probability of a certain wind direction = 0 (effect area category = I).
- Estimation of the frequency of occurrence:  
 $4 + 0.5 - 0.5 = 4$  which corresponds to:  $10^4$  accidents/year  
(from **Table 5.6**).

**Table 5.1. Average probability number ( $N_{i,s}^*$ ) for fixed installations.**

Substances (Reference numbers)	Activity	
	Storage	Processing plant
Flammable liquid (1 - 3)	8	7
Flammable liquid (4 - 6)	7	6
Flammable gas (7)	6	5
Flammable gas (9)	7	6
Flammable gas (10, 11)	6	—
Flammable gas (13)	4	—
Explosive (14, 15)	7	6
Toxic liquid (16 - 29)	5	4
Toxic gas (30 - 34)	6	5
Toxic gas (35 - 39)	6	—
Toxic gas (42)	5	4
Combustion products (43 - 46)	3	—

**Table 5.2. Probability number correction parameter ( $n_l$ ) for loading/unloading operations frequency.**

Frequency of loading/unloading <sup>a</sup> (yr <sup>-1</sup> )	Parameter
1 - 10	+ 0.5
10 - 50	0
50 - 200	- 1
200 - 500	- 1.5
500 - 2000	- 2

<sup>a</sup> For all kind of activities except pipelines and storage of cylinders (Reference number 13).

**Table 5.3. Probability number correction parameter ( $n_f$ ) for flammables.**

Substance (Reference number)	Safety measures – number of cylinders	Parameter
Flammable gas (7, 13)	sprinkler system	+ 0.5
Flammable gas (10)	double containment	+ 1
Flammable gas (13)	fire wall	+ 1
	sprinkler system	+ 0.5
	5 - 50 stored cylinders	+ 1
	50 - 500 stored cylinders	0
	> 500 stored cylinders	- 1

**Table 5.4. Probability number correction parameter ( $n_o$ ) for organizational safety <sup>a</sup>.**

Above average industry practice	+ 0.5
Average industry practice	0
Below average industry practice	- 0.5
Poor industry practice	- 1
Limited to non-existence organizational safety	- 1.5

<sup>a</sup> Several factors are included: safety management, age of the plant, maintenance, documentation and procedures, safety culture, training, emergency planning, etc.

**Table 5.5. Probability number correction parameter ( $n_p$ ) for wind direction towards populated area(s) in the affected zone.**

Effect area category	Part of the area (%) where people are living				
	100%	50%	20%	10%	5%
I	0	0	0	0	0
II	0	+ 0.5	+ 0.5	+ 0.5	+ 0.5
III	0	+ 0.5	+ 0.5	+ 1	+ 1.5

**Table 5.6. Conversion of probability numbers (N) into frequencies (P, event/yr) <sup>a</sup>.**

N	P	N	P	N	P
0	$1 \cdot 10^0$	5	$1 \cdot 10^{-5}$	10	$1 \cdot 10^{-10}$
0.5	$3 \cdot 10^{-1}$	5.5	$3 \cdot 10^{-6}$	10.5	$3 \cdot 10^{-11}$
1	$1 \cdot 10^{-1}$	6	$1 \cdot 10^{-6}$	11	$1 \cdot 10^{-11}$
1.5	$3 \cdot 10^{-2}$	6.5	$3 \cdot 10^{-7}$	11.5	$3 \cdot 10^{-12}$
2	$1 \cdot 10^{-2}$	7	$1 \cdot 10^{-7}$	12	$1 \cdot 10^{-12}$
2.5	$3 \cdot 10^{-3}$	7.5	$3 \cdot 10^{-8}$	12.5	$3 \cdot 10^{-13}$
3	$1 \cdot 10^{-3}$	8	$1 \cdot 10^{-8}$	13	$1 \cdot 10^{-13}$
3.5	$3 \cdot 10^{-4}$	8.5	$3 \cdot 10^{-9}$	13.5	$3 \cdot 10^{-14}$
4	$1 \cdot 10^{-4}$	9	$1 \cdot 10^{-9}$	14	$1 \cdot 10^{-14}$
4.5	$3 \cdot 10^{-5}$	9.5	$3 \cdot 10^{-10}$	14.5	$3 \cdot 10^{-15}$

<sup>a</sup> N is the absolute value of the logarithm of P ( $N = |\log_{10} P|$ ).



## 6. ESTIMATION OF PROBABILITIES OF MAJOR ACCIDENTS FOR TRANSPORTATION OF HAZARDOUS MATERIAL

To calculate the frequency ( $P_{t,s}$ , number of accidents/year) of accidents during transportation (subscript t) of a hazardous substance (subscript s) which causes the consequences that have been estimated in Section 4, the related so-called probability number ( $N_{t,s}$ ) should first be estimated.

$N_{t,s}$  can be calculated using the formula (6.1):

$$N_{t,s} = N_{t,s}^* + n_c + n_{t\delta} + n_p$$

where:

- $N_{t,s}^*$  = the average probability number for the transportation of the substance;
- $n_c$  = probability number correction parameter for the safety conditions of the transport system;
- $n_{t\delta}$  = probability number correction parameter for the traffic density;
- $n_p$  = probability number correction parameter for wind direction towards the populated area.

The probability number can then be converted into a probability, either using **Tab. 5.6** or directly, from the relationship between N and P:

$$N = |\log_{10} P|$$

### Procedural steps:

- Select one route (road/railway/waterway/pipeline); select a 1 km portion of that route; consider, within it, the place that is the most hazardous because of the unfavourable combination of high population density and low traffic safety (see also Section 3).

- If several hazardous substances are transported via this route, analyze each separately.

- Select in **Tab. 6.2** the average probability number for each hazardous substance (or group of substances; see also **Tab. 6.1**, which lists the international transport codes for flammable, toxic and explosive substances). This must be done for each identified portion of the routes under analysis.

- Estimate the probability number correction parameter  $n_c$  (**Tab. 6.3**).

This parameter takes into account the safety conditions of the transport system. The table is divided into two: **Tab. 6.3 (a)** shows general correction parameters data (the average corresponds to the one previously defined); **Tab. 6.3 (b)** shows the correction parameter for railways. A special attention must be given to shunting yards in railroads near industrial areas.

- Estimate the probability number correction parameter  $n_{t\delta}$  (**Tab. 6.4**).

This parameter takes into account the traffic density, i.e. the number of transport units (tank cars, rail cars, barges, etc.) per year, transporting this hazardous substance, or that are handled in one year on a shunting yard (rail). For underground pipelines  $n_{t\delta} = 1$  because they are used continuously.

The task of estimating the traffic density could be difficult and time-consuming. Owing to the scope of the present method, which allows only preliminary and rapid estimations, it is suggested to the user with limited information to perform more detailed analyses of the traffic in a section of a route only if it contributes significantly to the risk to the public.

- Estimate the probability number correction parameter  $n_p$  (**Tab. 5.5**).

This parameter, which is the same as already described in Section 5, takes into account the wind direction and the population distribution within a circle whose radius is the maximum distance of effect.

- Calculate the probability number  $N_{t,s}$  by the **formula (6.1)**.
- Convert the probability number into probability  $P_{t,s}$  by means of **Tab. 5.6** or directly, using the definition of  $N$ .
- If a portion of a road/railway/waterway/pipeline is exposed to the risk of accident from the transportation of different substances, the frequencies calculated for each of them have to be grouped under classes of injuries (defined in the section of societal risk). The obtained frequencies, which belong to the same class of injuries, must be eventually added. The number calculated for each class is the frequency per kilometer and per year of accidents which result in a number of fatalities included in the range that characterizes the class itself.
- Repeat all steps above for all the identified portions of commercial routes.

### 6.1. Example

A road 10 km long is being analyzed. Transportation of hazardous material includes: 4000 tank cars per year with LPG and 200 tank cars per year with gas of medium toxicity (e.g., ammonia). The attention of the analyst is focused on one section about 1200 m long because of deficiencies in traffic safety and a high density populated area at one side of the road.

#### Estimation

- Two separate calculations of the frequency of accident have to be performed because of the different characteristics of the substances. Hereafter, LPG transportation is identified by the symbol  $S_1$ , ammonia transportation by  $S_2$ .
- **Appendix 1, Table 3.1 (Checklist) and Table 4.1.a:**
  - LPG is a Flammable gas liquified by pressure: Reference number for  $S_1 = 7$ .
  - Ammonia is a Toxic gas medium: Reference number for  $S_2 = 31$ .
- **Table 4.1.a and Table 4.2:**

- LPG transported mass is in the range 10-50 t/tank car; effect category for  $S_1 = C I$  (maximum effect distance = 100 m; effect area = 3 ha).
- Ammonia transported mass is in the same range; effect category for  $S_2 = C III$  (maximum effect distance = 100 m; effect area = 0.3 ha).

• **Table 6.2:** Standard probability number:

- for  $S_1$  and  $S_2 = 9.5$ .

• **Table 6.3:** Probability number correction parameter for the safety conditions of the analyzed section of the road:

- for  $S_1$  and  $S_2 = -1$ .

• **Table 6.4:** Probability number correction parameter for traffic density:

- for  $S_1 = -3.5$ ;
- for  $S_2 = -2$ .

• **Table 6.5:** Probability number correction parameter for the distribution of population and wind direction:

- for  $S_1 = 0$  (effect area category = I).
- for  $S_2 = +0.5$  (effect area category = III; 50% populated).

■ Estimation of accident frequency (see **Tab. 5.6**):

$$\text{for } S_1 : \quad 9.5 - 1 - 3.5 = 5 \quad \Rightarrow 10^{-5} \text{ event/yr};$$

$$\text{for } S_2 : \quad 9.5 - 1 - 2 + 0.5 = 7 \quad \Rightarrow 10^{-7} \text{ event/yr.}$$

**Table 6.1. International Transport Codes.**

Substance (Reference number)	International transport codes
Flammable gas (7)	23 236 239
Flammable liquids (6)	33 336 338 339 333 x338 x323 x423 446 539
Toxic gases high (32)	26 265 266
Toxic gases medium (31)	236 268 286
Toxic liquids (19)	336 66 663
Explosives (14)	1.1 1.5

**Table 6.2. Average probability number ( $N_{t,s}^*$ ) for transport accidents <sup>a</sup>.**

Substances (Reference numbers)	Transport			
	Road	Rail	Water <sup>b</sup>	Pipeline
Flammable liquid (2)				6
Flammable liquid (5)				5
Flammable liquid (6)	8.5	10	7 9 <sup>c</sup>	
Flammable gas (7)	9.5	10.5		
Flammable gas (8)				6
Flammable gas (9)			10.5	
Flammable gas (11)			11.5	
Flammable gas (12)				6
Explosive (14)	9	11	8.5	
Toxic Liquid (19, 23, 27)	7	9		
Toxic Liquid (20, 24, 28)				
Toxic gas (31, 32)	9.5	10.5	10	
Toxic gas (36, 37)			9	
Toxic gas (40, 41, 42)				6 5 <sup>d</sup>

<sup>a</sup> The Table shows only the values that are necessary in the framework of the Manual.

<sup>b</sup> Inland waterways.

<sup>c</sup> Double hull.

<sup>d</sup> For substances that are very corrosive in contact with water.

**Table 6.3. Probability number correction parameter ( $n_c$ ) for the safety conditions of transport systems.**

**(a) General.**

	Road	Rail (b)	Ship	Pipeline
Safe <sup>1</sup>	+ 1		+ 0.5	+ 1
Average <sup>ii</sup>	-		-	-
Unsafe <sup>iii</sup>	- 1		- 0.5	- 1

- <sup>1</sup> Examples:
- Routes without crossings; routes with low or no traffic.
  - Roads with separate cart-roads.
  - Waterways: wide, straight.
  - Pipelines made with updated regulation and with specific measures.

<sup>ii</sup> Values to be used if it is not possible to categorize the route under the other two categories.

- <sup>iii</sup> Examples:
- Routes known to be frequently place of incidents.
  - Roads with a junction with high traffic; with a fork sharp bend; with no traffic lights; with slippery pave.
  - Waterways: with bends; with crossings; with traffic of ferries; with moorings for trans-shipment; with obstacles like bridges and locks.
  - Pipelines: if old; if made with out-of-date regulation; if their location is not known or if they are not indicated.

**(b) Rail transportation.**

Standard free track		-
Industrial track <sup>*</sup>		- 1
Shunting yards (or marshalling yards)	process with a hill	- 3
	process with locomotive and free riding cars	- 3
	process where cars are placed with a locomotive	- 2
	passing cars in bad conditions <sup>**</sup>	- 1
	shunting yard in bad conditions <sup>***</sup>	- 1

<sup>\*</sup> Especially branch-lines to facilities.

<sup>\*\*</sup> Leakages often occur; etc.

<sup>\*\*\*</sup> Free entrance to the place; wasted soil; bad conditions of the track; a process done by hand; etc.

**Table 6.4. Probability number correction parameter ( $n_{t,d}$ ) for traffic density.**

Number of vehicles/ships per year	Parameter
10 - 50	- 1.5
50 - 200	- 2
200 - 500	- 2.5
500 - 2000	- 3
2000 - 5000	- 3.5
5000 - 20000	- 4

**Table 6.5. Probability number correction parameter ( $n_p$ ) for wind direction towards populated area(s) in the affected zone.**

Effect area category	Part of the area (%) where people are living				
	100%	50%	20%	10%	5%
I	0	0	0	0	0
II	0	+ 0.5	+ 0.5	+ 0.5	+ 0.5
III	0	+ 0.5	+ 0.5	+ 1	+ 1.5



## 7. ESTIMATION OF SOCIETAL RISK

For each activity that has been analyzed (a fixed installation or a portion of road/railroad/waterway/pipeline), a pair of numbers have been calculated (or more than a pair in the case of different categories of substance, as previously described): (i) the number of fatalities (Section 4); and, (ii) the frequency of major accidents which result in that number of fatalities (Sections 5 and 6). The risk to the public from these activity is estimated by combining both values.

### Procedural steps:

- Classify each activity using a scale of consequence classes and a scale of probability classes.

These are defined as follows:

#### consequence classes:

0-25	fatalities/accident;
26-50	
51-100	
101-250	
251-500	
> 500	fatalities/accident.

**probability classes:** by one order of magnitude of the number of accidents per year.

- If a certain activity presents risk to the public from different substances which can cause accidents independently from each other, sum up the risk from substances which have the same class of consequences (example in Subsection 7.1).
- Place all the classified activities in a matrix of frequency vs. consequence for risk classification (example in Fig. 7.1).

Therefore, in a box of the matrix are listed all the activities which exhibit the same class of risk. All the hazardous activities in the area are thus shown on the one matrix of frequencies vs. consequences.

Frequency  
(accidents/year)

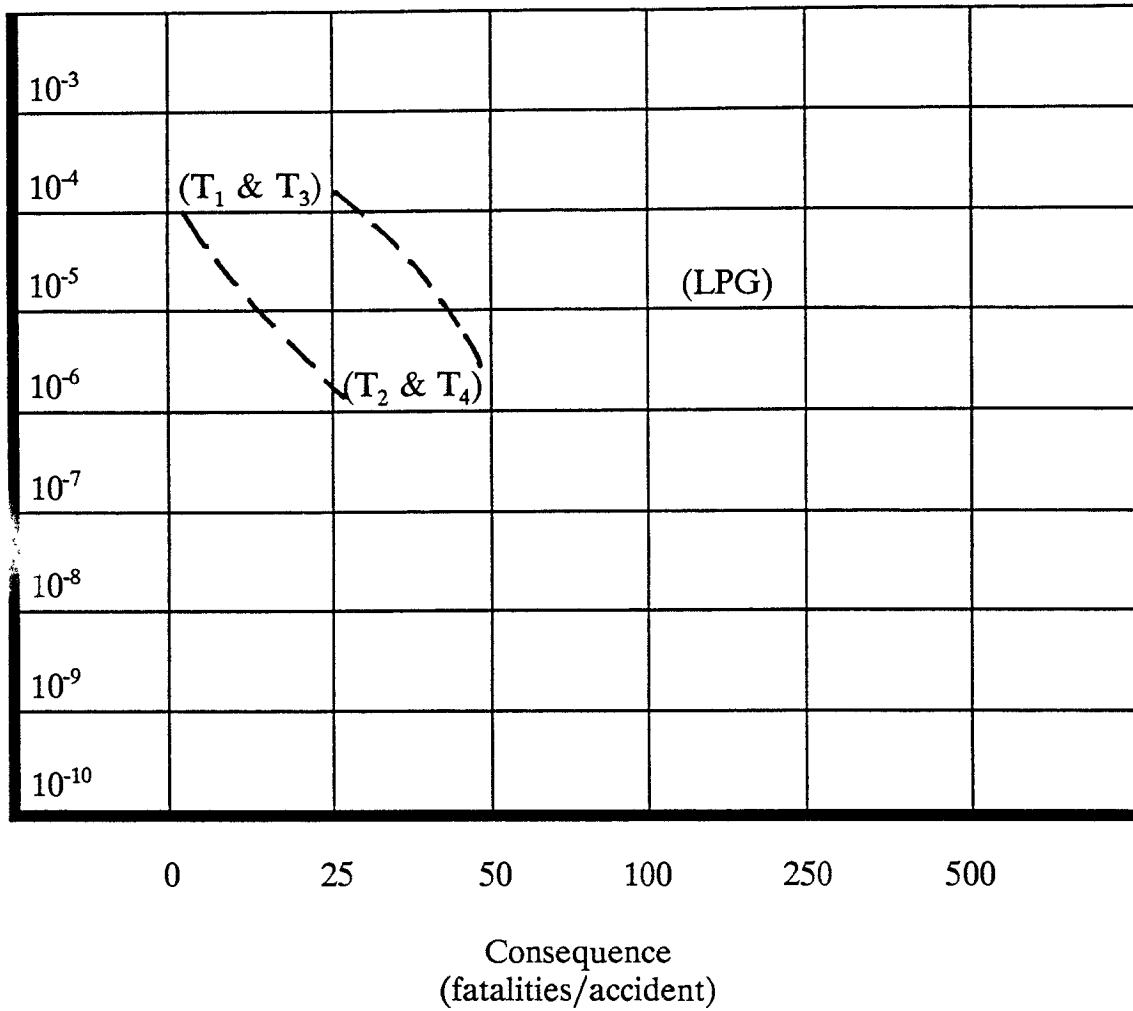


Figure 7.1. Matrix of frequency vs. consequence for risk classification (with example).

## 7.1. Example

An area has been analyzed with the methodologies explained in Sections 3-6. Two activities have been identified to present risk for the population: an LPG storage and the transport of four different hazardous substances, which are hereafter identified by the symbols  $T_1$ ,  $T_2$ ,  $T_3$  and  $T_4$ , in a section about 1 km long of a road. The following pair of values ( $C$  = fatalities/accident and  $P$  = yearly frequency of that accident) have been calculated:

LPG storage:  $C_{LPG} = 120$  fatalities/accident  
 $P_{LPG} = 3 \cdot 10^{-5}$  accident/year;

Road transport:

$C_{T1} = 6$  fatalities/accident  
 $P_{T1} = 10^{-5}$  accident/year;

$C_{T2} = 50$  fatalities/accident  
 $P_{T2} = 3 \cdot 10^{-6}$  accident/year;

$C_{T3} = 4$  fatalities/accident  
 $P_{T3} = 10^{-4}$  accident/year;

$C_{T4} = 45$  fatalities/accident  
 $P_{T4} = 10^{-6}$  accident/year.

### Estimation

- $C_{T1}$  and  $C_{T3}$  belong to the class of accidents which result in a number of fatalities  $< 25$ .
- $C_{T2}$  and  $C_{T4}$  are in their range 26-50 fatalities/accident.

Therefore,

$$P_{T1} + P_{T3} \approx 10^{-4} \text{ accidents/year;}$$

$$P_{T2} + P_{T4} \approx 4 \cdot 10^{-6} \text{ accidents/year.}$$

- The results can now be represented on the matrix of probability classes vs. consequence classes, which gives an overall picture of the risk in the area (**Fig. 7.1**).

## 8. PRIORITIZATION OF RISKS

A criterion (or criteria) for the acceptability of societal risk must be defined before the task is performed.

With reference to **Fig. 7.1**, the priority assessment risk categories correspond to the upper right-hand-side of the matrix of probability vs. consequence, i.e. activities with relatively high probability and high consequences. However, it has to be taken into consideration that the concept of societal risk also implies that risk of higher consequences but smaller frequency are perceived as more important than those of smaller consequences but higher probabilities.

The **criteria of acceptability** can be established in various ways:

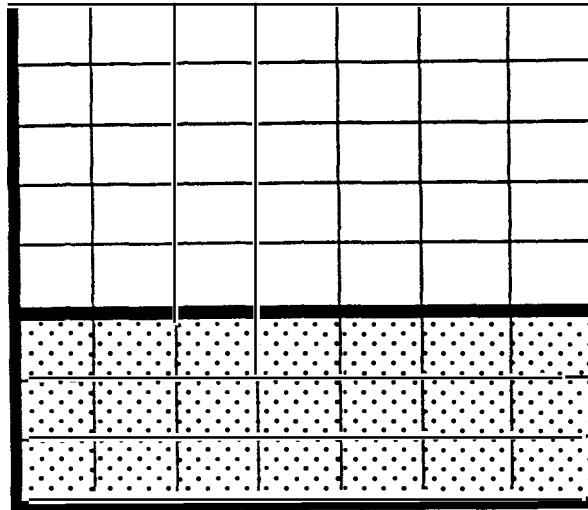
- by setting a threshold for the class of consequences only (**Fig. 8.1 (a)**); or,
- by setting a threshold for the probability classes only (**Fig. 8.1 (b)**); or,
- by considering a combination of both classes (**Fig. 8.1 (c)**).

The latter case could be derived by one of the existing criteria for societal risk. As an example, **Fig. 8.2** shows the criteria used in the Netherlands.

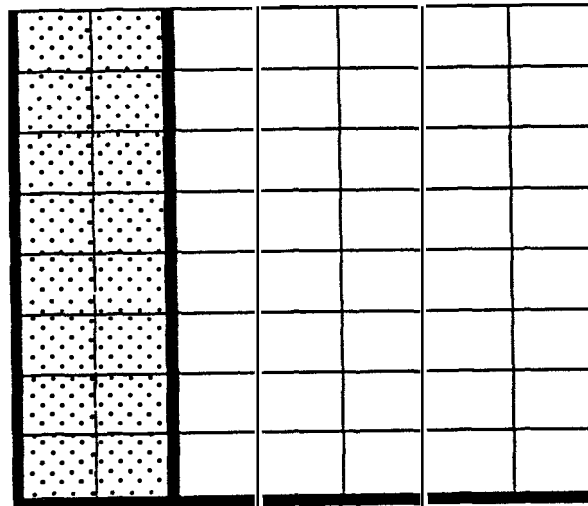
### **Procedural steps:**

- Identify on the matrix of frequency vs. consequence all the activities which do not meet the selected criteria (i.e., all the activities whose calculated risk is beyond the acceptability).
- The list of all these activities is the final product of the task.

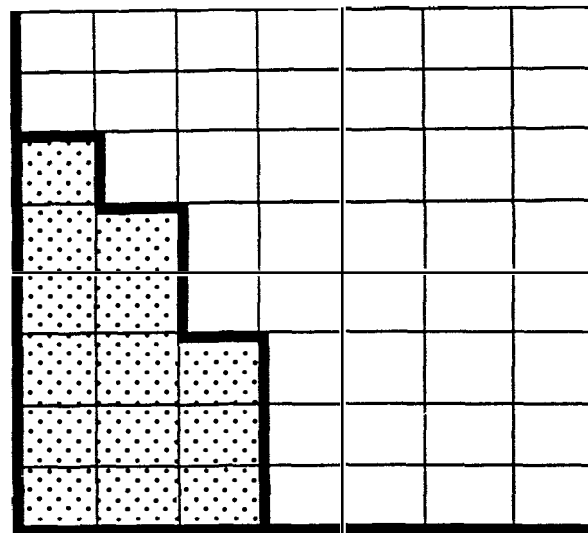
Frequencies



(a)



(b)



(c)

Consequences

**Figure 8.1.** Options for the acceptability criteria for societal risk – classes of risk in non-shadowed areas are not acceptable.

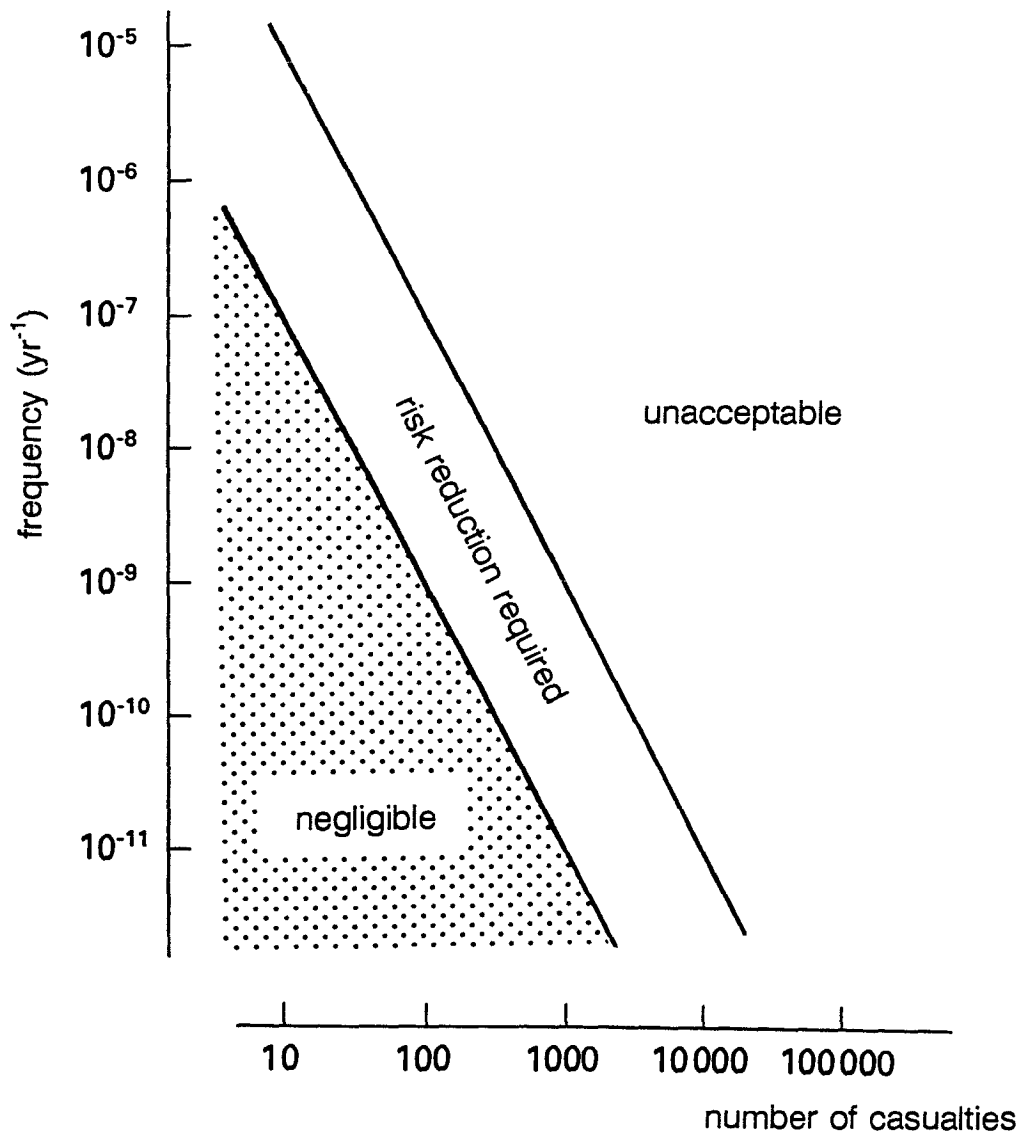


Figure 8.2. Societal risk acceptability criteria in the Netherlands.

## 9. NOTE ON IMPLEMENTATION

- The setting of a criterion or of a set of criteria for the prioritization of activities, whose risks are to be assessed in more details and in priority to other activities, is a matter for individual countries.

It is not within the scope of the Manual to recommend any particular criterion for risk acceptability or tolerability. The criteria adopted in the Netherlands is one of very few that have been formalized to date and as such is highlighted by way of example.

- By way of general guidance, activities with risks of relatively high consequences vs. high probability and those of relatively high consequences vs. low probability may be considered candidates for detailed assessment, relative to those of low consequences vs. high probability.

- Two cases of final results may be obtained:

Case (i): Activities are scattered throughout the consequence vs. probability matrix, enabling classification and prioritization directly along the principles indicated above.

Case (ii): All activities fall within one region (either above or below) of the consequences vs. probability acceptable criteria line. In this case, an additional criterion should be considered for further prioritization. This could be based on either a line of consequences only, or probability only, or by shifting the consequences vs. probability criteria line to lower values.

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- [17] SAVE II, Computer software package, SAVE.
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- [19] TECHNICA, SAFETI, Computer software package.
- [20] TNO, Effects, Computer software package.
- [21] CPR, Methods for calculating physical effects (Yellow book) (1988).
- [22] CPR, Methods for calculating damage (Green book) (1990).



## Appendix 1

### List of substances

Reference number	Type of substance	Substances (examples)
1 - 3	Flammable liquid vapour pressure < 0.3 bar at 20°C (flash point > 20°C)	Allyl alcohol Aniline Benzaldehyde Benzyl chloride Butanol Butyl diglycol Dichlorobenzene Dichloropropene Diesel oil Diethyl carbonate Dimethylformamide Ethanolamine Ethyl formate Ethylglycol acetate Ethyl silicate Ethylene chlorohydrin Ethylene glycol Fuel oil Furfural Furyl carbinol Isoamyl alcohol Isobutanol Isopropanol Methyl butyl ketone Methyl glycol Methyl glycol acetate Naphthalene Nitrobenzene Oil Phenol Styrene Trioxane Xylene

### List of substances (continued)

Reference number	Type of substance	Substances (examples)
1 - 3	Flammable liquid vapour pressure < 0.3 bar at 20°C (flash point ≤ 20°C)	Acetal Acetaldehyde Acetone Acetonitrile Benzene Benzyl chloride Butanedione Butanol Butanone Butyl chloride Butylformate Cyclohexene Dichloroethane Dichloropropane Diethylamine Diethyl ketone Dimethyl carbonate Dimethylcyclohexane Dioxane Ethanol Ethyl acetate Ethyl acrylate Ethylbenzene Ethyl formate Heptane Hexane Isobutyl acetate Isopropyl ether Methanol Methyl acetate Methylcyclohexane Methyl isobutyl ketone Methyl methacrylate Methyl propionate Methyl vinyl ketone Octane Piperidine Propyl acetate Pyridine Toluene Triethylamine Vinyl acetate

### List of substances (continued)

Reference number	Type of substance	Substances (examples)
4 - 6	Flammable Liquid vapour pressure $\geq$ 0.3 bar at 20°C	Carbon disulphide Collodion solution Cyclopentane Diethyl ether Ethyl bromide Isopropene Isopropyl alcohol Methyl formate Naphtha Natural gas condensate Pentane Petrol Propanol (propyl alcohol) Propylene oxide
7 - 9	Flammable gas liquefied by pressure	1,3-butadiene Butane Butene Cyclopropane Difluoroethane Dimethyl ether Ethane Ethyl chloride Isobutane Isobutylene LPG Methyl ether Propadiene Propane
10, 11	Flammable gas liquefied by cooling <sup>a</sup>	Ethene Methane Methyl acetylene Natural gas (LNG)
12	Flammable gas under pressure	Ethylene Hydrogen Methane Methyl acetylene Natural gas (LNG)
13	Flammable gas in cylinders	Acetylene Butane Hydrogen LPG Propane

<sup>a</sup> See also list of flammable gases liquified by pressure (Reference numbers 7-9).

### List of substances (continued)

Reference number	Type of substance	Substances (examples)
14, 15	Explosive	Ammonium nitrate (fertiliser type A1) Ammunition Nitroglycerine TNT
16, 17	Toxic liquid low	Acethyl chloride Allylamine Allyl bromide Allyl chloride Chloropicrin Dichlorodiethyl ether Dimethylhydrazine Dimethyl sulphide Epichlorohydrin Ethanethiol Ethyl isocyanate Ethyltrichlorosilane Iron pentacarbonyl Isopropylamine Methacrolein Methyl hydrazine Osmium tetroxide Perchloromethylthiol Phosphorous oxychloride Phosphorous trichloride Sulphuryl chloride Tetraethyl lead Tetramethyl lead Trichlorosilane Vinylidene chloride

List of substances (continued)

Reference number	Type of substance	Substances (examples)
18 - 21	Toxic liquid medium	Acrolein Acrylonitrile Bromine Carbon Sulphide Chloroacetaldehyde Chloromethylether Cyanogen bromide Dimethyldichlorosilane Ethyl chloroformate Ethyleneimine Isobutylamine Methyl chlorine tomate Methyldichlorosilane Methyl iodide Methyltrichlorosilane Nitric acid (fuming) Oleum (fuming sulphuric acid) Pentaborane Propylene imine Propylene oxide Tin tetrachloride
22, 25	Toxic liquid high	Hydrogen cyanide Nitrogen dioxide Sulphur trioxide Tert-butylamine
26, 29	Toxic liquid very high	Methyl isocyanate Nickel carbonyl Sulphur pentafluoride
30, 35	Toxic gas low	Ethylamine Ethylene oxide Vinyl chloride
31, 36, 40	Toxic gas medium	Ammonia Boron trifluoride Carbon monoxide Chlorine trifluoride Dimethylamine Hydrogen fluoride Nitrogen trifluoride Perchloryl fluoride Silane Sulphur dioxide Trimethylamine Vinyl bromide

### List of substances (continued)

Reference number	Type of substance	Substances (examples)
32, 37, 41, 42	Toxic gas high	Boron trichloride Carbonyl sulphide Chlorine Chlorine dioxide Dichloroacetylene Formaldehyde Hexafluoroacetone Hydrogen bromide Hydrogen chloride Hydrogen sulphide Methyl bromide Methyl chloride Nitrogen monoxide Silicon tetrafluoride Sulphuryl fluoride Tin tetrahydride
33, 38	Toxic gas very high	Boroethane Carbonyl chloride Carbonyl fluoride Cyanogen Dimethyl ether Fluorine Ketene Oxygen difluoride Phosgene Phosphine Stibine Sulphur tetrafluoride Tellurium hexafluoride
34, 39	Toxic gas extreme	Arsine Hydrogen selenide Ozone Selenium hexafluoride