IAEA-TECDOC-727 (Rev.1)

Manual for the classification and prioritization of risks due to major accidents in process and related industries

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

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FOREWORD

Industrial development is essential to raise the standard of living in all countries. This requires the building of refineries, power stations and other large industrial complexes. However, human health can be affected, directly or indirectly, by routine discharges of waste from industrial installations. The environment is adversely affected by emissions from power stations and the accumulation of industrial wastes. Releases of toxic materials can have disastrous effects on both health and the environment. A series of major industrial accidents in the 1970s and 1980s highlighted the need for better management of risks in routine industrial operations and from accidents.

Past efforts to cope with these risks, if any, have been largely piecemeal. Some plants are well equipped to manage environmental hazards while others are not. Some risk management studies have concentrated on occupational hazards and some on threats to the environment such as pollution, while others concentrated on contingency planning for major accidents. Very few have considered all risks.

If risks can be assessed and managed on a comprehensive basis, then scarce resources can be deployed more effectively and industrial development can be facilitated. Developing countries, in particular, have much to gain from adopting a sound approach to management of the risks associated with industrial development.

The IAEA, the United Nations Environment Programme (UNEP), the United Nations Industrial Development Organization (UNIDO) and the World Health Organization (WHO) decided in 1986 to join forces in order to promote the use of integrated area wide approaches to risk management. The Inter-Agency Programme brings together expertise in health, the environment, industry and energy — all vital for effective risk management.

The purpose of the Inter-Agency Programme is to develop a broad approach to the identification, prioritization and minimization of industrial hazards in a given geographical area. This is one of a series of publications intended to be issued on behalf of the four participating UN organizations.

This is the first revision of the original report, distributed in December 1993. The revision was undertaken in the light of experience with the original edition and was prompted by the wish to add the results of a practical case study and some new developments.

Although some figures have been updated, this does not mean that the results of calculations based on the original publication are no longer useful.

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EDITORIAL NOTE

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, the transfer of knowledge and experience amongst countries in the application of these procedures and the implementation of an integrated approach to risk management.

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

The UN organizations sponsoring this programme have been involved for several years in activities aimed at assessment and management of environmental and health risks, prevention of major accidents and emergency preparedness. This Manual has been developed on the basis of experience from these activities, to assist in 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 risk assessment and management processes.

The first version of the Manual was distributed in draft form on a limited scale for comment and validation of the proposed methods. It should be stressed that working with rough estimations and average accident scenarios, as are used in this method, can give no answer to questions such as the maximum number of people who may be killed or injured in an accident, or the maximum effect distance. As an example, the method can be useful for prioritization of actions in the field of emergency preparedness, but the method is less useful for working out a specific emergency preparedness plan for a (selected) industrial activity.

Several countries made comments over the period August 1991 to May 1992 (Colombia, India, Italy, Netherlands, Switzerland, the USA) which were taken into account in the report which was published in 1993. This report presented, in fact, a third generation of ranking methods. The first generation, an inventory procedure, was developed by D. van den Brand for the province of South Holland and is available only in Dutch. The second generation was developed by TNO Environmental and Energy Research, Netherlands, on request and was based mainly on the ideas of D. van den Brand. These second generation guidelines have been translated into several languages and are called "The Guide to Hazardous Industrial Activities". The first version of IAEA-TECDOC-727 represents the third generation; although using much of the same technical data, it has its own purpose and various important additions as well as a step by step approach not used in earlier work.

The revised version of IAEA-TECDOC-727 does not contain changes in substance but presents an improved presentation of the methodology.

This Manual was prepared at three Consultants Meetings held in Vienna, in August 1991, December 1992 and September 1995 by:

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CONTENTS

1. INTRODUCTION

1.1. OVERVIEW

There is a growing need in both developed and developing economies to ensure that risks to people, property 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 into consideration of the social and economic benefits to the community is high on the agenda in most governments. Equally, there is need to ensure efficient and optimum allocation of limited resources in 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 within 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 due to major accidents with off-site consequences in fixed installations handling, storing and processing hazardous materials; and in the transport of hazardous materials by road, rail, pipeline and inland waterway. The types of risk being considered are risks to public health from fires, explosions and releases of toxic substances 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 any one member of the general public will be killed as a 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 although only a rough characteristic graph of the real societal risk has been described.

(c) The assumptions used in estimating the consequences of accidents indicated in the Manual are such that maximum consequences might be larger than those described. Consequences and the probability of scenarios by which consequences are estimated are related to each other. The consequence estimations are based on average weather conditions and 100% fatalities within an area defined by certain effect criteria (e.g. fires, explosions).

Uncertainties in criteria used (e.g. LC_{50} values) as well as the relatively limited influence of some given effects within the affected area (e.g. heat radiation and over pressure by vapour cloud explosions) leads to rough estimates of effects which are chosen to compare the risks of different industrial activities as conveniently and as logically as possible.

1.3. AREAS OF APPLICATION

Large industrial areas (see Fig. 1) include an extensive number of risk sources and activities of varying nature and extent. Such sources may include operating process plants, storage terminals, transport activities, etc. The same applies at the individual plant level where a number of sources of risk of varying magnitude exist.

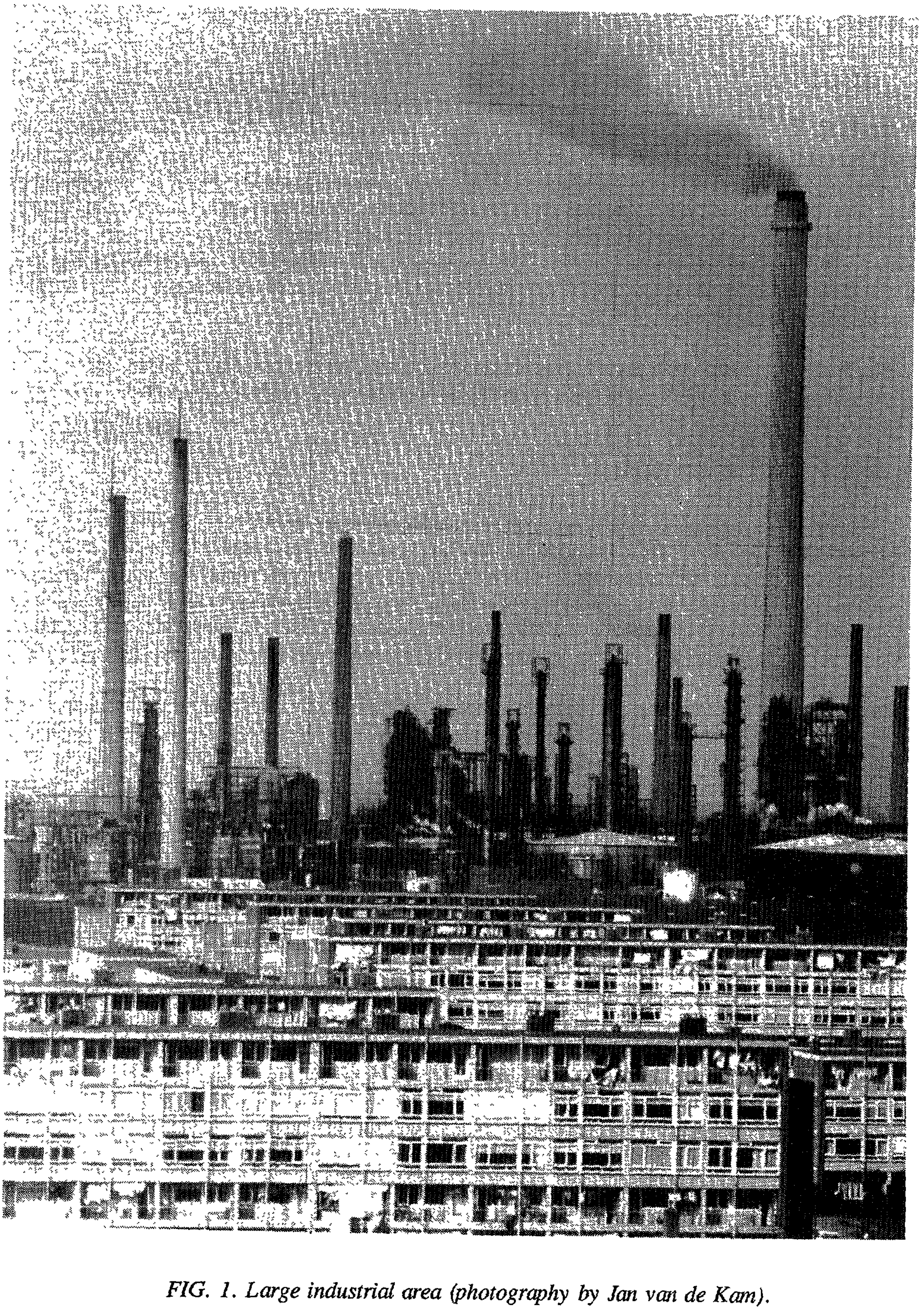


FIG. 1. Large industrial area (photography by Jan van de Kam).

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 and where assessment resources should be allocated for the highest return on efforts.

The main assumptions of the method are:

- Only the most important variables have been used in assessing probabilities and consequences of accidents (e.g. population density, traffic safety, frequency of loading/unloading operation).
- The assessments of consequences and probabilities have been made by using categories which differ from each other by up to one order of magnitude.

The assumptions of fatality criteria are that:

- There is 100% lethality in an area where physical or toxic effects are assumed to give 50–100% lethality;
- Outside this area no fatalities are counted;
- Mitigation factors depend on the type of substance used.

The assumptions for consequence calculations are:

- Consideration of three typical effect categories: circular (e.g. explosions), half circular (e.g. heavy cloud), elongated (e.g. dispersion);
- Effect distances up to 10 000 m;
- Substance categories for flammables, explosives and toxics up to five subcategories are needed (for toxics);
- Calculations of different activities related to process, storage and transport of substances.

The assumptions for probability calculations are:

- Average failure frequencies based on historical experience;
- Correction factors related to the differences between industrial activities;
- Development of a method by using the 'probability numbers' concept (see Section 5).

The method discriminates among the risks from industrial activities, which may differ by up to one order of magnitude.

■ **The methods and results indicated in the Manual can be used:**

(a) To provide a preliminary generalized quantitative overview of the different risks in a large industrial area, based on the concept of (health) societal risk;

(b) To enable the prioritization 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 presented 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 the transport of hazardous materials if the decision making process in a specific situation depends on differences for which a more detailed analysis is requested;

  (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;

  (e) For making an emergency plan for a specific situation where such 'risks' exist (e.g. a plant in an inhabited area, transport of dangerous materials near inhabited areas).

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 leads the user to calculate approximately the number of fatalities caused by an accident in a fixed installation or in the transport of hazardous materials. The estimation of probabilities yields 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 co-ordinates 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 one matrix format. The user can identify all the activities which do not satisfy the requirements, just by drawing a line in the matrix and, based on national policy, determine which probabilities and/or consequences are serious enough for further steps in the risk management process. The purpose of using the Manual is to obtain a list of activities whose risks have to be further analysed 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, weather stability class D with wind velocity 5 m/s has been chosen. It has to be stressed that this is not the worst situation, but is just an assumption taking into consideration an average weather condition with the purpose of comparing toxics, flammables and explosives.

- Fatality criterion for fires:

  100% fatalities of the persons exposed within the fire area. The heat flux is not taken into account in this Manual. A heat flux of 5–10 kW/m^2 for 30 s can give serious injuries; however, most injuries would not be lethal (1%).

- Fatality criteria for explosions:

  For a vapour cloud explosion, 100% fatalities among the persons engulfed in the volume of the burning cloud; lower flammability limit ignition criterion assumed (i.e. ignition occurs for vapour concentration $\geq$LFL). The overpressure is not taken into account. The overpressure (by deflagration of an unconfined vapour cloud max 0.3 bar) can give serious injuries due to mechanical damage, although the percentage of fatalities are relatively low. For explosives, 100% fatalities in the immediate vicinity of the centre of detonation, which means high overpressures >1 bar and a high density of flying fragments.

- Fatality criterion for toxic clouds:

  100% fatalities among the persons exposed for more than 30 min to a concentration $\geq LC_{50}$ for humans. Although this is an overestimation within the defined affected area, it is an underestimation outside the affected area where lower but still lethal concentrations can exist.

  Due to the chosen fatality criteria, it has to be stressed that an affected area calculated in this Manual is smaller than the area where there is (still) a certain probability of death or where there could be injuries.

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

TABLE I. OVERVIEW OF THE MAIN TASKS FOR THE RISK CLASSIFICATION AND PRIORITIZATION SCHEME

Tasks	Section in Manual
Classification of type of activities and inventories	3
Estimation of consequences	4
Estimation of probabilities:	
Fixed installations	5
Transport	6
Estimation of societal risk	7
Prioritization of risks	8

A summary description of the procedural steps is provided in the following:

- 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 hazardous fixed installations and all routes and methods of transport 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 populated area; the distribution of population in the area; and possible mitigating actions.

- Estimation of probabilities of major accidents

  Fixed installations

  The method is based on the estimation of average frequencies, incorporating corrections on specific operations (loading/unloading), safety systems, organizational and safety management and the probability of wind direction towards populated areas in the affected zone.

  Transport of hazardous material

  The method is based on the estimation of average frequencies of major accidents for each hazardous substance (or group of substances) identified for each portion of road/railway/waterway/pipeline under analysis, incorporating corrections on: the safety conditions of the transport system; the traffic density; and the probability of the wind direction being towards populated areas in the affected zone.

For the convenience of the users of the Manual, frequencies and probabilities are given and calculated with the negative values of the exponent of the number ten ("7" = 10^{-7}; "5.5" = 3×10^{-6}, etc).

- 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 versus consequence.

- Prioritization of risks

  The estimation of societal risks of all individual activities can be represented on the matrix so that an activity which does not meet the requirements can be easily recognized. By drawing a line in the matrix, based on national policy, it can be determined which probabilities and/or consequences are serious enough to decide on further steps in the risk management process.

3. CLASSIFICATION OF TYPES 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 I shows a useful list of hazardous substances. Throughout the report, the substances are identified by a reference number.

3.1. PROCEDURAL STEPS

- Define the boundaries of the area; describe the area. Maps of different scales are essential.

  The area chosen is, for example, an area ruled by one (local) governmental body or an area with important industrial activities and/or important areas of habitation. Normally this results in an area as large as 10–200 km^2.

  It is also possible to use this Manual to prioritize specific industrial activities in a country (e.g. shunting yards, in which case the user needs only information and tables related to shunting yards in this Manual, the same can be done for the ammonia chain, e.g. its production process, storage and transport in which case one has to use the information and tables related to ammonia and the specific activity, depending on the objectives of the user).

- Collect information on all hazardous activities in the area. Divide into fixed installations and transport: name, location, type, production, storage conditions; name, physical state and amount of hazardous substances. The checklist shown in Table II can be used.

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

- Classify the activities under different types by the checklist shown in Table II.

- Exclude from the classification scheme the hazardous activities that do not present direct harm to the public because of the distance from populated areas; the criterion of selection for both fixed installations and transport is shown in Table III(a).

- Exclude from the study the routes with infrequent transport of hazardous substances — the criterion of traffic density is shown in Table III(b).

- In the case of inland waterways, in general one could ignore the transport of soluble liquids (vapour pressure < 1 bar at 20°C) and the transport of substances with specific mass greater than 1 kg/dm^3 (density greater than water density). Be aware of products which can give specific chemical reactions with water, in which case the amount of hazardous reaction products that can be released must be estimated.

- Selected roads/railways/waterways/pipelines have to be divided into portions of 1 km (the probability figures given in the Manual are based on 1 km portions). The portions which do not meet the criterion of separation distance to populated areas in Table III(a) can be ignored. Within each portion, select the place closest to populated areas. In the case of transport by rail, particular attention has to be paid to shunting yards. For water, particular attention has to be paid to harbours.

- Consider the inventory of hazardous substances and the layout of the facility. Estimate conservatively the maximum amount that could realistically be involved in an accident. If a facility has physical and 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). Physical separation is a sufficient distance between storage vessels. Efficient separation is 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 to be good physical/efficient separations.

TABLE II. CHECKLIST

Activity		Most important substances	Reference numbers (Table IV)
Fuel storage	Delivery station	Petrol	6
	Car station	Petrol and LPG	7
	Intermediate depot	Petrol	6
		LPG	7, 9
	Main storage	Oil	1, 3
		Petrol	4, 6
		LPG	7, 9,10, 11
		Natural gas	10, 11
	Gas cylinder storage	Various gases	13
Processing and storage of fuel	Refinery	LPG propane	7, 9
	Alkylation process	Hydrogen fluoride	31
	Naphtha cracker	Butylene	7, 9
		Ethylene	12
		Ethylene oxide	30
		Propylene	7, 9
		Vinyl chloride	7, 9
Transport of fuel	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
Extensive cooling installation	Abattoir, dairy, brewery, margarine, icecream, chocolate industries, storage of meat, fish, fruit, flowers, ice rink	Ammonia	31
Food and stimulants	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 II. (cont.)

Activity		Most important substances	Reference numbers (Table IV)
Specific basic products	Leather industry	Acroleine acids	18, 21
	Wood industry	Formaldehyde	32
	Paper industry	Ethylene oxide	30
		Epichlorohydrine	16, 17
	Rubber industry	Styrene	4, 6
		Acrylonitril	18, 21
	Textile auxiliaries	Ethylene oxide	30
		Formaldehyde	32
		Alkyl phenols	
Metallurgical, electronic industries	Blast furnaces	Carbon monoxide	31
		Ammonia	31
	Surface treatment	Arsine	34
Specific chemicals	Fertilizers	Ammonia	31, 36
		Combustion products	43
	Sulphuric acid	Sulphur oxides	45
	Synthetic resins	Ethylene oxides	30
		Chlorine	32
		Acrylonitrile	18, 21
		Phosgene	33
		Formaldehyde	32
	Plastics/synthetics	Vinyl chloride	7, 9
		Acrylonitrile	18, 21
		Chlorine	32
		Combustion products	46
	Paints/pigments	Phosphene	33
		Solvents	4, 6
		Combustion products	46
	Chloro-fluorocarbons (CFCs)	Hydrogen chloride	40, 42
		Chlorine	32
		Hydrogen fluoride	31
	Chlorine	Chlorine	32, 37
	Vinylchloride	Chlorine	32
		Vinyl chloride	7, 9
		Hydrogen chloride	40, 42
	Ammonia	Ammonia	31, 36
	Hydrogen chloride	Hydrogen chloride	40, 42
		Chlorine	32
	Fibres	Carbon disulphide	18
		Hydrogen sulphide	32
	Drugs/pharmaceuticals	Chlorine	32
		Solvents	4, 6
	Polymerization	Butylene	7, 9
		Ethylene	12
		Propane	7, 9
		Vinyl acetate	1, 3
	Synthetic fibre	Methanol	1, 3
	Chlor alkali	Chlorine	32
		Hydrogen	12

TABLE II. (cont.)

Activity		Most important substances		Reference numbers (Table IV)
Pesticides	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
Explosives	Production and storage	Various		14
	Storage of ammunition	Various		14, 15
Public places and utilities	Waterworks	Chlorine		32
	Storage of pesticides	Combustion products		43
Harbour facilities	Containers	Various		[a]
	Tanks (storage facilities)	Various		[a]
Transport	Pipelines	Chlorine		41
		Ammonia		40
		Ethylene oxide		40
		Hydrogen chloride		41, 42
	Road and rail (also shunting yards)	Flammable gases[b]:	23, 236, 239	7
		Flammable liquids[b]:	33, 336, 338 339, 333, x338, x323, x423, 446 539	6
		Toxic gases high[b]:	26, 265, 266	32
		Toxic gases medium[b]:	236,268, 286	31
		Toxic liquids[b]:	336, 66, 663	19
	Water	Explosives[b]:	1.1, 1.5	14
		Flammable gases[b]:	23, 236, 239	9[c], 11[d]
		Flammable liquids[b]:	33, 336, 338 339,333, x338 x323,x423, 446, 539	6
		Toxic gases high[b]:	26, 265, 266	32[c], 37[d]
		Toxic gases medium[b]:	236,268, 286	31[c], 36[d]
		Toxic liquids [b,e]:	336, 66, 663	20

[a] See Appendix I for specific reference numbers.
[b] International classification codes for transport (also in Table IV).
[c] Pressurized.
[d] Cooled.
[e] Insoluble; specific weight ≤ 1 kg/dm^3.

TABLE III(a). CRITERIA FOR THE SELECTION OF INDUSTRIAL ACTIVITIES TO BE INCLUDED IN THE STUDY

(a) Criterion of distance from populated areas[a] (first dwellings)

Industrial activity			Distance from populated areas (m)
Stationary installations	flammable substances and/or explosives		<1000
	specifically:		
	- petrol station		<50
	- LPG station		<100
	- pipeline with flammable liquids		<50
	- storage of cylinders (25–100 kg)		<100
	toxic substances		<10 000
	specifically:		
	- cooling installation		<100
	- storage of pesticides for retail		<50
Transport	LPG, by:	rail/road	<200
		water	<500
	petrol, by:	rail/road	<50
		water	<200
	oil, by:	rail/road	<25
		water	<100
	toxic substances, by:	rail/road	<3000
		water	<3000

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

TABLE III(b). CRITERIA FOR THE SELECTION OF INDUSTRIAL ACTIVITIES TO BE INCLUDED IN THE STUDY

(b) Criterion of traffic density

Industrial activity				Traffic density (number of units/a)
Transport	gas, by:	road		>50
		rail		>500
			on shunting yards	>50
		water		>500
	liquids, by:	road		>50
		rail		>5000
			on shunting yards	>50
		water		>50
	explosives, by:	road		>20
		rail		>200
			on shunting yards	>20
		water		>20

4. ESTIMATION OF CONSEQUENCES OF MAJOR ACCIDENTS TO HUMANS

- Which consequences?

Once sufficient information on the hazardous activities in the area has been gathered and structured as indicated in Section 3, the consequences of major accidents can be calculated for each selected activity. Depending on the objectives of the decision maker one can make a differentiation between the internal and external consequences.

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 around the facility where the hazardous activity takes place, or where hazardous substances are transported. Internal consequences are fatalities amongst people working on or visiting the facility or, in the case of transport, people taking part of the traffic themselves.

- Calculation

The 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 Eq. (1).

$$C_{a,s}=A \times \delta \times f_A \times f_d \times f_m \tag{1}$$

where:

A = Affected area - Tables IV and V (hectares; 1 ha = 10^4 m^2)
δ = population density in defined populated areas (persons/ha)
f_A = correction factor for populated area (part of circle) (–)
f_d = correction factor for populated area (distances) (–)
f_m = correction factor for mitigation effects.

It should be clear that the estimation of consequences must be the worst case. This worst case situation depends on wind direction (effect areas II and III) and can be found by comparing the actual population statistics in the area where (depending on wind direction) the effect area given in the Tables IV and V could be (Figs 2, 3).

Apart from using the above equation one could use a map and a transparency with the effect area drawn on. Just by turning the transparency around (in the case of an effect area II or III), one can estimate the number of people involved. In that case the consequences $C_{a.s}$ can be calculated by using the simple equation $N \times f_m$. For examples see Figs 4(a–d).

For fixed installations: all people living or working off-site have to be taken into account. The user has to decide whether he or she wants to take account of people working on or visiting the site itself.

For transport routes: as with fixed installations. The user has to decide whether he or she wants to take account of people travelling by road. When taking motorists, etc. into account, be aware of traffic jams (which will increase the number of people involved) that could be a result of the accident itself.

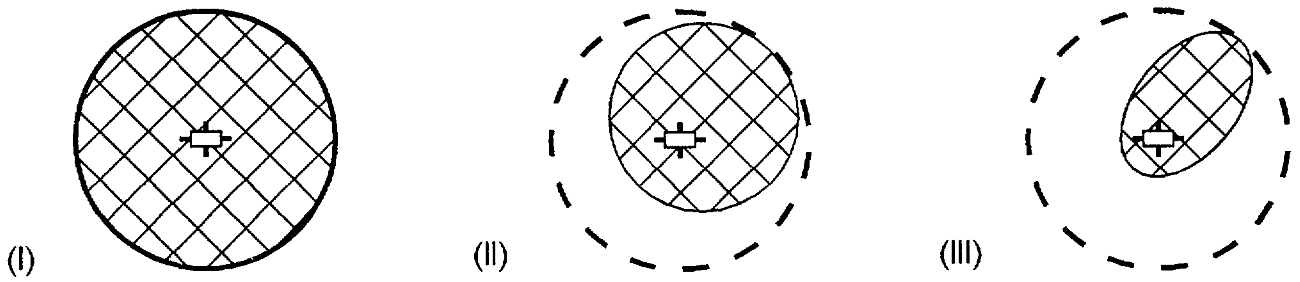


FIG. 2. Illustration of the effect area categories.

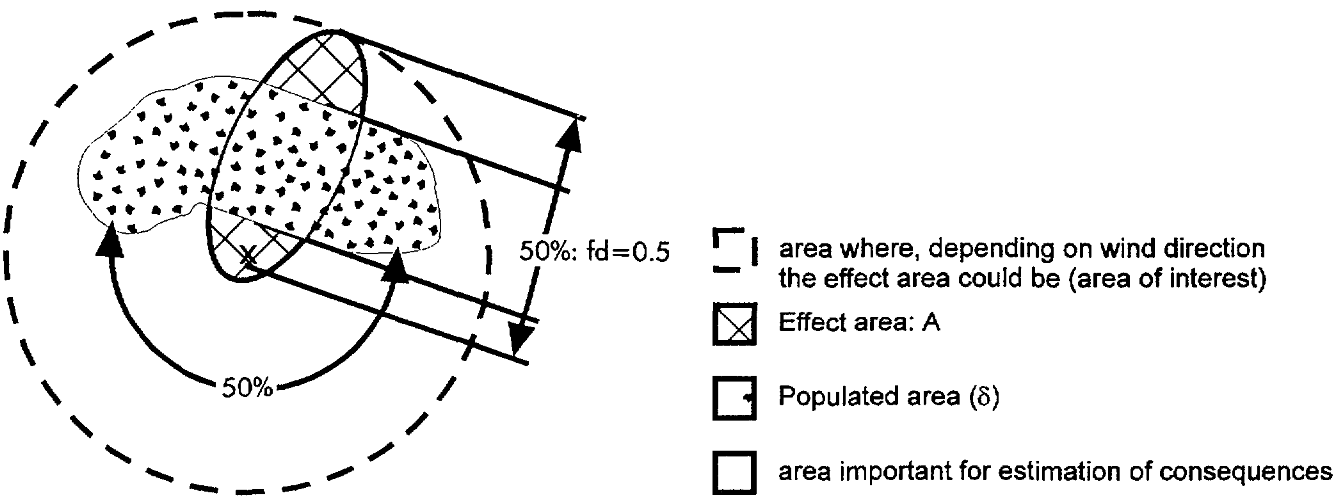
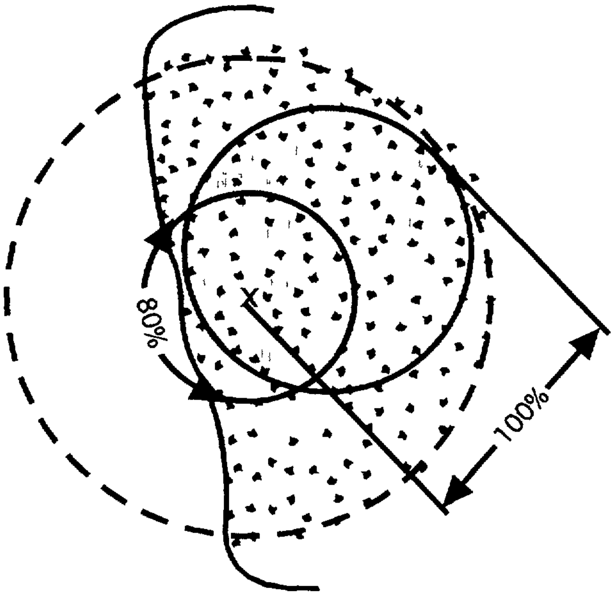


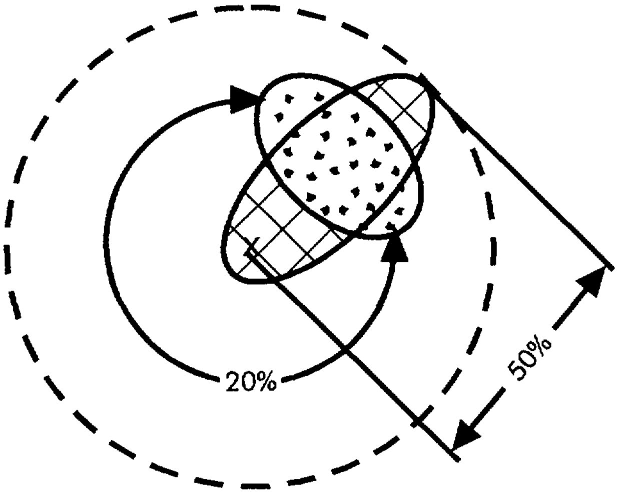
FIG. 3. Example with effect area category III.



- Effect area (Table IV) A. cat II
- Populated area δ (Table VI)
- Population fraction (part of circular affected area) about 80% $f_A = 1$ (Table V)
- Population fraction (related to distances) 100% $f_D = 1$
- f_m = (Table VIII)

$$C_{a,s} = A \times \delta \times 1 \times 1 \times f_m$$

FIG. 4(a). Illustrations of estimating consequences.



- Effect area (Table IV) A. cat III
- Populated area δ (Table VI)
- Population fraction (part of circular affected area) about 20% $f_A = 1$ (Table V)
- Population fraction (related to distances) 50% $f_D = 0.5$
- f_m = (Table VIII)

$$C_{a,s} = A \times \delta \times 1 \times 0.5 \times f_m$$

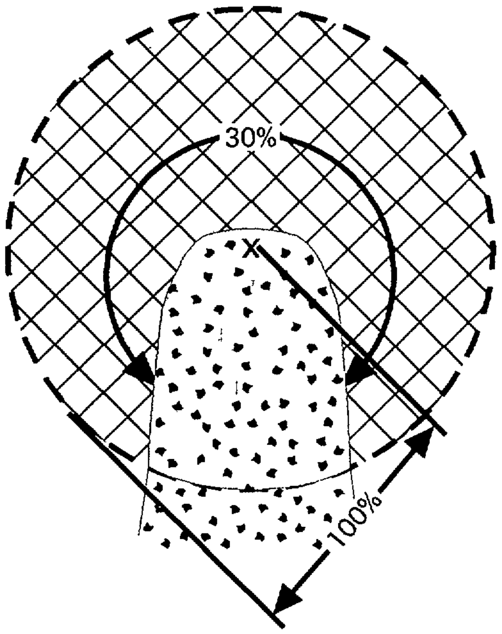
area of interest (always a circle with as the centre the place of the accident)

Effect area (A) cat I, II or III

Populated area (δ)

(estimated) area of consequences

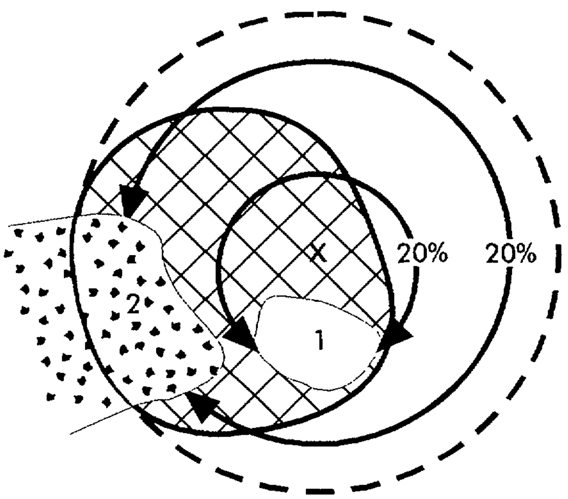
FIG. 4(b). Illustrations of estimating consequences.



- Effect area (Table IV) A. cat I
- Populated area δ (Table VI)
- Population fraction (part of circular affected area) about 30% $f_A = 0.3$ (Table V)
- Population fraction (related to distances) 100% $f_D = 1$
- f_m = (Table VIII)

$$C_{a,s} = A \times \delta \times 0.3 \times 1 \times f_m$$

FIG. 4(c). Illustrations of estimating consequences.



- Effect area (Table IV) A. cat II
- Populated areas δ_1 (Table VI)
  δ_2 (Table VI)
- Population fraction (part of circular affected area)
  (1) = 20% $f_{A1} = 0.4$
  (2) = 20% $f_{A2} = 0.4$
- Population fraction (related to distances)
  (1) = 50% $f_{D1} = 0.5$
  (2) = 30% $f_{D2} = 0.3$
- f_m = (Table VIII)

$$C_{a,s} = A \times \delta 1 \times 0.4 \times 0.5 \times f_m + A \times \delta 2 \times 0.4 \times 0.3 \times f_m$$

area of interest (always a circle with as the centre the place of the accident)

Effect area (A) cat I, II or III

Populated area (δ)

(estimated) area of consequences

FIG. 4(d). Illustrations of estimating consequences.

4.1. PROCEDURAL STEPS

- Select one of the activities.

- If more than one substance in the same activity can cause damage independently from the other substances, analyse 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. After following the procedures it will be clear whether flammable properties are important or not, compared with toxic properties.

- Classify the activity using Tables IV(a) and IV(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 (Table IV(a)).

  In the case of a pipeline, the key parameter for classification is its diameter (Table IV(b)).

  The definition of the effect categories (or classes) is shown in Table V. The categorization is by means of two effect categories: the maximum distance of effect (meters) and the affected area (hectares).

- Record the maximum distance of effect (related to the letters A–H) and the affected area (related to the Roman numerals I–III and the letters A–H) from Table V.

- Estimate the distribution of population within the circular area whose radius is the maximum distance of effect. Estimate the density of population 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 Table VI, on the basis of the generic description of the area.

- Estimate the area correction factor f_A

  The factor is one out of two calculation parameters to estimate the surface of the populated area (with population density δ) within the effect area. To find f_A one should estimate the average angle of the populated area within the circular area of interest and estimate the percentage:

$$\frac{angle^{\,o}}{360^{\,o}} \times 100\%$$

  One can find f_A by using Table VII.

- Estimate the area correction factor f_d

  The factor is the other of two calculation parameters to estimate the surface of the populated area (with population density δ) within the effect area. To find f_d one should estimate the fraction of "the length or depth" of the populated area compared with the radius of the area of interest.

- $f_A \times f_d$ gives an estimation of the fraction of the populated area within the effect area. One may check this visually.

- Estimate the correction factor f_m (proposed values in Table VIII).

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

  For example, in the case of an explosion, opportunities for mitigation 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.

  Exposed persons could then take effective protective action such as fleeing, sheltering, etc.

- Calculate the external consequences $C_{a,s}$ using the Eq. (1).

- Repeat all steps above for all important substances by all stationary activities and transport routes.

TABLE IV(a). CLASSIFICATION OF SUBSTANCES BY EFFECT CATEGORIES

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

[a] Categories for pipelines are shown in Table IV(b).

TABLE IV(a). (cont.)

Ref. No.	Quantity (t)								
	0.2–1	1–5	5–10	10–50	50–200	200–1000	1000–5000	5000–10000	> 10000
1	–	–	–	–	–	A I	B I	B I	C I
2[a]	–	–	–	–	–	–	–	–	–
3	–	–	–	A I	B I	C I	D II	X	X
4	–	–	–	–	–	B I	C II	C II	D II
5[a]	–	–	–	–	–	–	–	–	–
6	–	–	–	B II	C II	D II	E II	X	X
7	–	AI	BI	C I	D I	E I	X	X	X
8[a]	–	–	–	–	–	–	–	–	–
9	–	BII	CIII	C III	D III	E III	X	X	X
10	–	–	–	–	–	B I	C II	C II	D II
11	–	–	–	B II	C II	D II	E II	X	X
12[a]	–	–	–	–	–	–	–	–	–
13	–	–	C III	C II	C I	C I	X	X	X
14	AI	BI	BI	CI	CI	DI	X	X	X
15	BIII	BIII	CIII	CI	CI	DI	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	–	AII	C III	D III	X	X	X	X	X
20	–	BII	D III	E III	F III	G III	X	X	X
21	–	BII	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	BII	CII	D III	E III	X	X	X	X	X
24	CII	DII	E III	F III	G III	G III	X	X	X
25	BII	CII	D III	E III	F III	F III	G III	X	X
26	AII	BII	C III	E III	F III	G III	G III	H III	H III
27	CII	DIII	E III	F III	X	X	X	X	X
28	DIII	EIII	F III	G III	H III	H III	X	X	X
29	CIII	DIII	E III	F III	G III	H III	H III	X	X
30	AII	BII	B II	CIII	C II	DIII	D III	D III	E III
31	BII	CII	C II	DIII	E III	F III	F III	G III	H III
32	CII	DIII	E III	E III	F III	G III	G III	X	X
33	DIII	EIII	F III	G III	G III	H III	X	X	X
34	EIII	FIII	G III	H III	H III	X	X	X	X
35	–	–	–	A II	A II	B II	B II	C II	D III
36	–	AII	B II	C II	D III	D III	E III	F III	G III
37	BII	CII	D III	E III	E III	F III	F III	G III	H III
38	DIII	EIII	F III	F III	G III	G III	X	X	X
39	EIII	FIII	G III	H III	H III	X	X	X	X
40[a]	–	–	–	–	–	–			
41[a]	–	–	–	–	–	–			
42[a]	–	–	–	–	–	–			
43	–	–	–	B II	D III	E III	E III	X	X
44	–	AII	A II	C III	E III	F III	F III	X	X
45	–	–	A II	B 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.
[a] Categories for pipelines are shown in Table IV(b)

TABLE IV(b). CLASSIFICATION BY EFFECT CATEGORIES OF SUBSTANCES FLOWING IN UNDERGROUND PIPELINES OUTSIDE PLANTS

Ref. No.	Type of substance	Description of substance	Diameter[a] (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 0.1–0.2 >0.2	C I D I E I
12		Under pressure	0.2–1 >1	A I B I
40	Toxic gas	Medium toxicity	<0.1 0.1–0.2	E III F III
41		High toxicity	<0.1 0.1–0.2	F III G III
42		Pressure >25 bar, high toxicity	<0.02 0.02–0.04 0.04–0.1	D III E III F III

[a] Diameter of the largest pipe.

TABLE V. EFFECT CATEGORIES: MAXIMUM DISTANCE AND AREA OF EFFECT

Effect distance (m) category		Effect area category (ha)[a]		
		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	3000–10 000	–	–	1000

[a] 1 ha = 10^4 m^2.

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 (see Fig. 2) is defined by one value which is the estimated affected area, in hectares.

- Notation I corresponds to the circular area with the maximum distance of effect as diameter (a circular effect as estimated in the case of a detonation of explosives);
- Notation II to the area of the semicircle (a typical heavy flammable gas cloud which may have delayed ignition and/or a cloud caused by evaporation of a large pool;
- Notation III to about 1/10 of the area of the circle (an elongated cloud caused by dispersion). A distance category can be found in combination with each area category. The exception of F, G and H, which combine only with the area category III, can be explained by the fact that these distances are related to the dispersion of large amounts of toxic gases in elongated clouds (see Fig. 3).

4.2. EXAMPLE

A storage of petrol contains 2000 t. It is provided with tank pit (bund). A village could be affected by a major accident; 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 m from the storage. The village occupies 20% of the area within 100 m from the storage.

Estimation

Appendix I, Table II (Checklist) and Table IV(a):	Storage of petrol with tank pit (reference number 4).
Table IV(a):	2000 t: Effect category = C II.
Table V:	Effect category C II corresponds 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 Tables VI and VII:

Table VI:	Population density in the village = 20 persons/ha.
Table VII:	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 VIII:	Correction factor for mitigation = 1 (flammable substance, reference number 4).

Estimation of the number of fatalities:

1.5 (ha) × 20 (persons/ha) × 0.4 ×1 = 12 fatalities.

TABLE VI. POPULATION DENSITY

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 VII. 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 VIII. 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, 37-39, 40-42)	0.1
Toxic gas	(35-36)	0.05

These factors are based on:

- whether measures should be taken depending on the way an effect occurs the duration of an effect (for instance: the period of time between an accident and the time that the estimated effect occurs);
- if people within the exposed area have a chance to protect or shelter themselves.

5. ESTIMATION OF PROBABILITIES OF MAJOR ACCIDENTS FOR FIXED INSTALLATIONS

To calculate the frequency ($\mathbf{P}_{i,s}$, 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 Eq. (2):

$$N_{i,s} = N^*_{i,s} + n_l + n_f + n_o + n_p \tag{2}$$

where:

$N^*_{i,s}$ = the average probability number for the installation and the substance;

Within the present methodology N is defined as 'probability number'. This 'probability number' has always attached an equivalent frequency value P. The relationship between N and P is:

$N = |\log_{10} \mathbf{P}|$ (see also Table XIV)

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.

5.1. PROCEDURAL STEPS

- Select one of the activities.
- If more than one substance can cause damage independently from the other substances, analyse 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 (Table IX).
- Estimate the probability number correction parameter n_l (Table X(a)).

  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 (Table XI).

  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 (Table XII).

  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; and the existence of emergency and evacuation plans, etc. Care should be taken in estimating the parameter, especially if the facility cannot be directly surveyed.

- Estimate the probability number correction parameter n_p (Table XIII).

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

  In particular, the parameter does not apply to 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 (see Fig. 5).

  The values shown in Table XIII are calculated assuming a uniform distribution of the frequencies of wind directions in rising wind.

- Calculate the probability number $N_{i,s}$ using Eq. (2).

- Convert the probability number into probability $\mathbf{P}_{i,s}$ by means of Table XIV or directly, using the definition of N.

- Repeat all steps above for all stationary activities.

5.2. EXAMPLE

A storage of 1700 cylinders of 40 kg of weight containing propane and butane has 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 I, Table II (Checklist) and Table IV(a):	Storage of flammable gas (reference number 13).
Table IV(a), Table V:	Total mass of gas = $0.04 \cdot 1700$ = 68 t; effect category = C I (effect distance = 100 m; effect area = 3 ha).
Table IX:	Standard probability number = 4.
Table X(a):	To be skipped (see note by Table X(a)).

Table XI:	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 XII:	Probability number correction parameter for management, etc.: we assume that for the activity under analysis = -0.5.
Table XIII:	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 (from Table XIV):

4 + 0.5 - 0.5 = 4, which corresponds to 10^{-4} accidents/year.

TABLE IX. 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 X(a). PROBABILITY NUMBER CORRECTION PARAMETER (n_l) FOR LOADING/UNLOADING OPERATIONS FREQUENCY

Frequency of loading/unloading[a] (per year)	Parameter
1-10	+0.5
10-50	0
50-200	-1
200-500	-1.5
500-2000	-2

[a] For all activities except pipelines and storage of cylinders (reference number 13). When calculating the consequences it is important to be aware of the quantity of hazardous material in the loaded/unloaded tank of the ship, rail/road, tank/car or road tank/car. For a ship it is also important to take into account the possibility of collisions in the harbour (see Table X(b)).

TABLE X(b). PROBABILITY NUMBER CORRECTION PARAMETER (n_l) FOR LOADING/UNLOADING OPERATIONS FREQUENCY (cont.)

Apart from loading/unloading operations, collisions between ships in a harbour are possible which can give damage of a loading/unloading ship.

(I) Number of ships passing by in the harbour a year:

300-3000	-3
3000-30 000	-4
30 000-300 000	-5

(II) Number of loading/unloading ships a year:

30-300	-2
300-3000	-3
3000-30 000	-4

(III) Average period of time for one loading/unloading activity:

1 hour	0
3 hours	-0.5
10 hours	-1

Probability number can be found by:

10 + (I) + (II) + (III)

The consequence calculation is made on the basis of the contents of one of the (average) tanks within the (average) loading/unloading ship.

TABLE XI. 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 sprinkler system 5–50 stored cylinders 50–500 stored cylinders >500 stored cylinders	+1 +0.5 +1 0 -1

TABLE XII. PROBABILITY NUMBER CORRECTION PARAMETER (n_o) FOR ORGANIZATIONAL SAFETY[a]

Above average industry practice	+ 0.5
Average industry practice	0
Below average industry practice	- 0.5
Poor industry practice	- 1
Non-existent safety practices	- 1.5

[a]Several factors are included: safety management, age of the plant, maintenance, documentation and procedures, safety culture, training, emergency planning, etc.

Although it is known that the parameters described here are of importance for the estimation of risks, it is not possible to give a routine method to allow for all such factors. Work in this field has been done by Technica UK and the University of Leiden, Netherlands, but only for a limited number of detailed specific studies. Such specific analyses were not the objective of the present Manual.

TABLE XIII. 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 XIV. CONVERSION OF PROBABILITY NUMBERS (N) INTO FREQUENCIES (P, event/year) [a]

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	$3 \cdot 10^{-15}$

[a] N is the absolute value of the logarithm of **P** ($N = |\log_{10} \mathbf{P}|$).

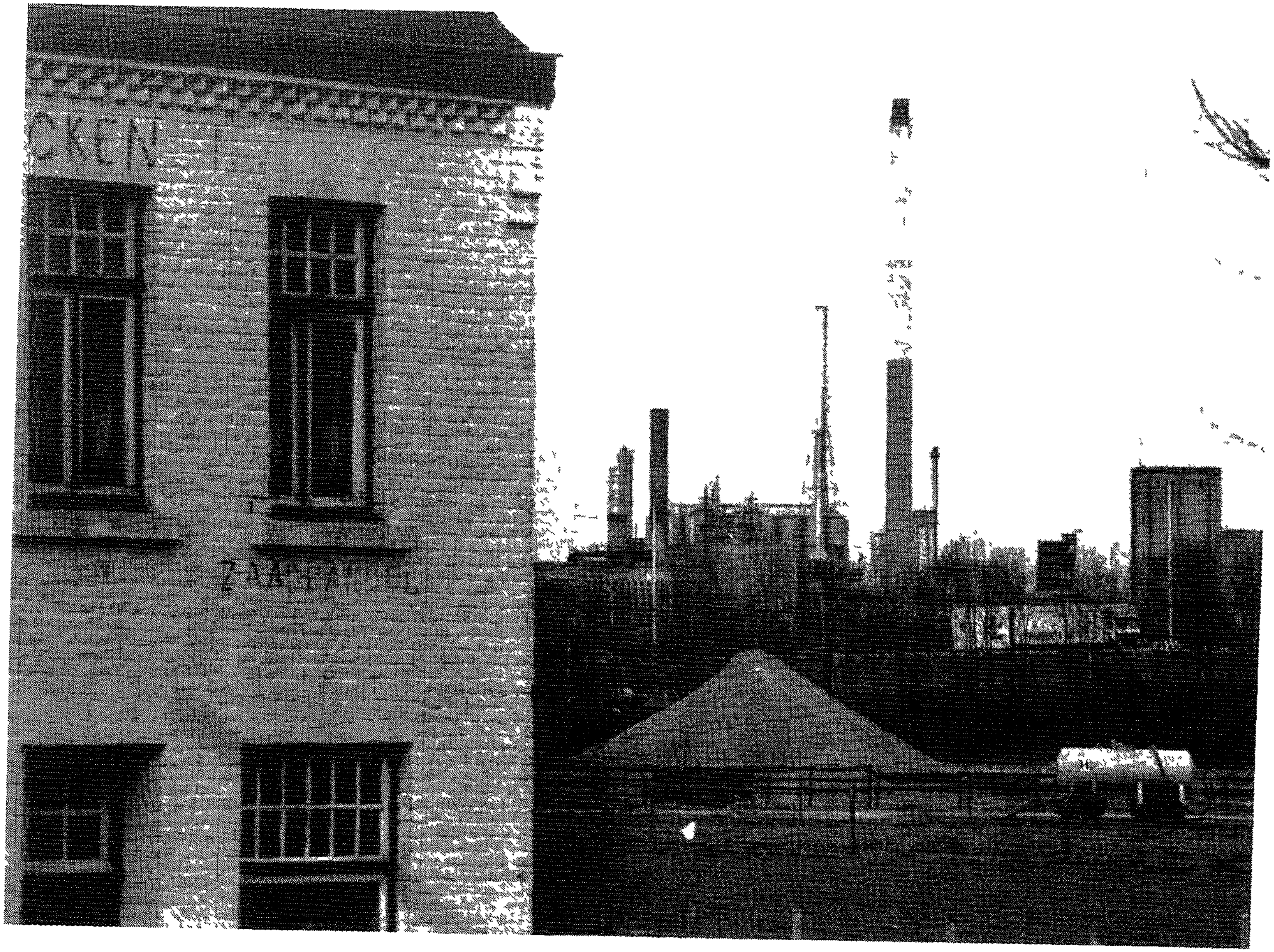


FIG. 5. Living areas near industrial activities (photography by Michiel Sablerolle).

6. ESTIMATION OF PROBABILITIES OF MAJOR ACCIDENTS FOR TRANSPORT OF HAZARDOUS MATERIAL

To calculate the frequency (**$P_{t,s}$**, number of accidents/year) of accidents during transport (subscript t) of a hazardous substance (subscript s) which results in 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 Eq. (3):

$$N_{t,s} = N^*_{t,s} + n_c + n_{t\delta} + n_p \qquad (3)$$

where:

$N^*_{t,s}$ = the average probability number for the transport of the substance;

Within the present methodology N is defined as 'probability number'. This 'probability number' is always attached an equivalent frequency value P.

The relationship between N and P is:

$N = |\log_{10} \mathbf{P}|$ (see Table XX)

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.

6.1. 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, analyse each separately.

- Select in Table XV the average probability number for each hazardous substance or group of substances (see also Table XVI 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 (Table XVII).

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

- Estimate the probability number correction parameter $n_{t\delta}$ (Table XVIII).
  This parameter takes into account the traffic density, i.e. the number of transport units (tank cars, rail cars, barges, etc.) per year used to transport this hazardous substance, or the number that are handled in one year on a shunting yard (rail). However, do not use this table for pipelines.

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

- Estimate the probability number correction parameter n_p (Table XIX).

  This parameter, previously 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 $N_{t,s}$ using Eq. (3).

- Convert the probability number into probability $\mathbf{P}_{t,s}$ by means of Table XX or directly, using the definition of N.

- If a portion of a road/railway/waterway/pipeline is exposed to the risk of accident due to the transport of different substances (see Figs 6 and 7), the frequencies calculated for each substance have to be grouped under classes of injuries (defined in the section of societal risk). The frequencies obtained, which relate to the same class of injuries, must eventually be added. The number calculated for each class is the frequency per kilometre 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.

6.2. EXAMPLE

The risks associated with a road 10 km long are being analysed. Transport 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, lacking in traffic safety with a densely populated area at one side of the road.

Estimation

Two separate calculations of the frequency of accident have to be performed due to the different characteristics of the substances. Hereafter, LPG transport is identified by the symbol S_1, ammonia transport by S_2.

Appendix I, Table II (Checklist) and Table IV(a):	LPG is a flammable gas liquefied by pressure: reference number for $S_1 = 7$.
	Ammonia is a toxic gas medium: reference number for $S_2 = 31$.
Table IV(a) and Table V:	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 II (maximum effect distance = 100 m; effect area = 1.5 ha).
Table XV:	Average probability number: for S_1 and S_2 = 9.5.

Table XVII:	Probability number correction parameter for the safety conditions of the analysed section of the road: for S_1 and S_2 = -1.
Table XVIII:	Probability number correction parameter for traffic density: for S_1 = -3.5; for S_2 = -2.
Table XIX:	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 = II; 50% populated).

Estimation of accident frequency (from Table XX):

for S_1 : $9.5 - 1 - 3.5 = 5$ ===> 10^{-5} event/year;
for S_2 : $9.5 - 1 - 2 + 0.5 = 7$ ===> 10^{-7} event/year.

TABLE XV. AVERAGE PROBABILITY NUMBER ($N^*_{l,s}$) FOR TRANSPORT ACCIDENTS[a]

Substances (reference numbers)		Transport			
		Road	Rail	Water[b]	Pipeline
Flammable liquid	(2)				6
Flammable liquid	(5)				5
Flammable liquid	(3, 6)	8.5	9.5	7.5 9[c]	3
Flammable gas	(7)	9.5	10.5		
Flammable gas	(8)				6
Flammable gas	(9)			10	
Flammable gas	(11)			9	
Flammable gas	(12)				6
Explosive	(14)	9	10	8	
Toxic liquid	(19, 23, 27)	7.5	8.5		
Toxic liquid	(20, 24, 28)			6.5 8[c]	
Toxic gas	(31, 32)	9.5	10.5	9	
Toxic gas	(36, 37)			8	6
Toxic gas	(40, 41, 42)				5[d]

[a] The table shows only the values that are necessary in the framework of the Manual.
[b] Inland waterways.
[c] Double hull.
[d] For substances that are very corrosive in contact with water.

TABLE XVI. INTERNATIONAL TRANSPORT CODES (IMDG–RID–ADR–ADNR)

Substance	(Reference number)	International transport codes
Flammable gas	7	combination first digit 2 and a digit 3
Flammable liquids	6	combination first digit 3 and a digit 3
Toxic gases high	32	26 265 266
Toxic gases medium	31	236 268 286
Toxic liquids	19	first digit 6 first digit 8 combination first digit 3 and digit 6
	23, 27	all combinations of 6 and 8
Explosives	14	1.1 1.2 1.5

For toxics only it is necessary to work with UN numbers in combination with the list of substances in Appendix I.

TABLE XVII. PROBABILITY NUMBER CORRECTION PARAMETER (n_c) FOR THE SAFETY CONDITIONS OF TRANSPORT SYSTEMS

(a) Road, ship and pipeline transport

	Road	Ship	Pipeline
Safe[a]	+1	+0.5	+1
Average[b]	–	–	–
Unsafe[c]	-1	-0.5	-1

[a] 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.

[b] Values to be used if it is not possible to categorize the route under the other two categories.

[c] 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 transshipment; 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.

In reality the real figures for 'safe' and 'unsafe' can have even a larger deviation from the average than the figures given in the table.

(b) Rail transport

Standard free track	Standard	–
	Mixed trains (correction for gases)	- 1
Industrial track[d]		- 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
	process where only complete trains are handled	-1
	passing cars in bad conditions[e] or shunting yard in bad conditions[f]	- 1

[d] Especially branch lines to facilities.
[e] Leakages often occur; etc.
[f] Free entrance to the place; wasted soil; bad conditions of the track; a process done by hand; etc.

TABLE XVIII. PROBABILITY NUMBER CORRECTION PARAMETER ($n_{t\delta}$) 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
5000–20 000	-4

TABLE XIX. 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 XX. CONVERSION OF PROBABILITY NUMBERS (N) INTO FREQUENCIES (P, event/year) [a]

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	$3 \cdot 10^{-15}$

[a] N is the absolute value of the logarithm of **P** ($N = |\log_{10} \mathbf{P}|$).

FIG. 6. Mobile hazardous activities (photography by Michiel Sablerolle).

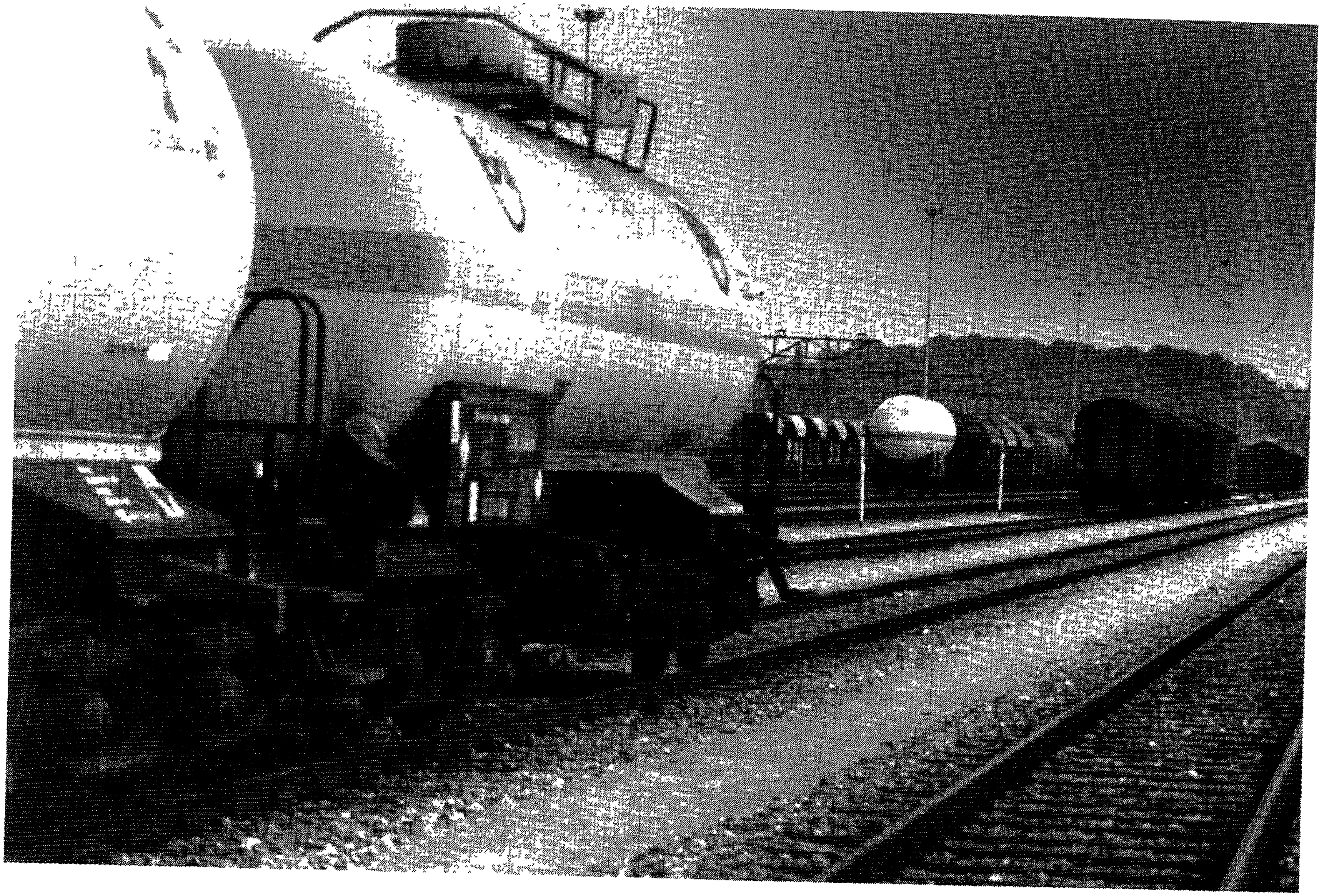


FIG. 7. Rail transport systems: a shunting yard (photography by Michiel Sablerolle).

FIG. 8. *Consequences of industrial accidents (photography by Roel Dijkstra, Netherlands).*

7. ESTIMATION OF SOCIETAL RISK

For each activity that has been analysed (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 activities is estimated by combining both values (see Fig. 8).

7.1. 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
  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 Section 7.2).

- Place all the classified activities in a matrix of frequency versus consequence for risk classification (example in Fig. 9).

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

7.2. EXAMPLE

An area has been analysed with the methodologies explained in Sections 3–6. In a section of a road about 1 km long two activities have been identified to present risk to 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). 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 the range 26–50 fatalities/accident.

  Therefore,

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

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

- The results can now be represented on the matrix of probability classes versus consequence classes, which gives an overall picture of the risk in the area (Fig. 9).

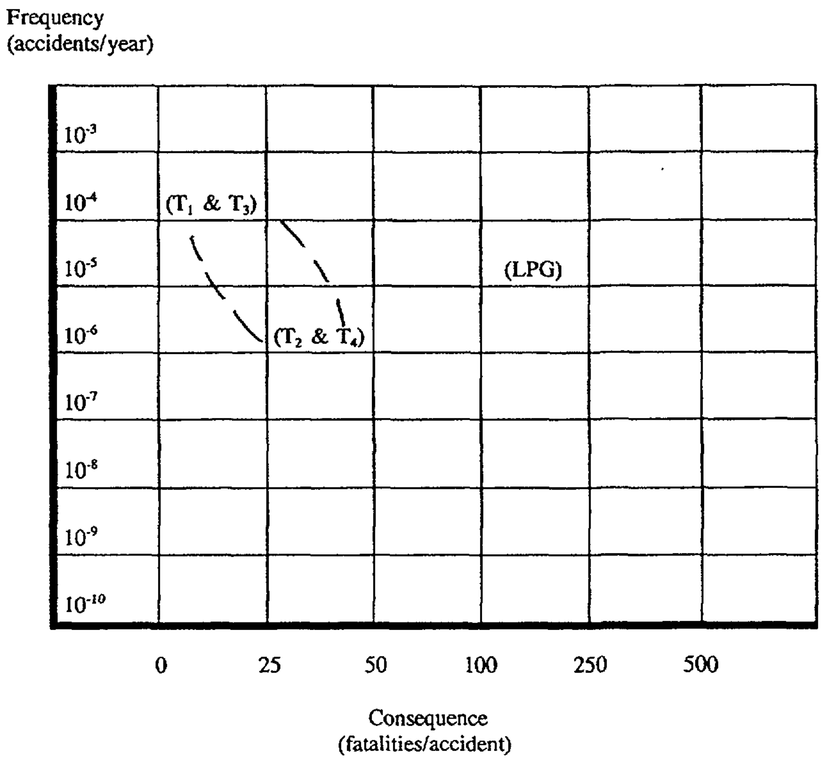


FIG. 9. Matrix of frequency versus consequence for risk classification (with example).

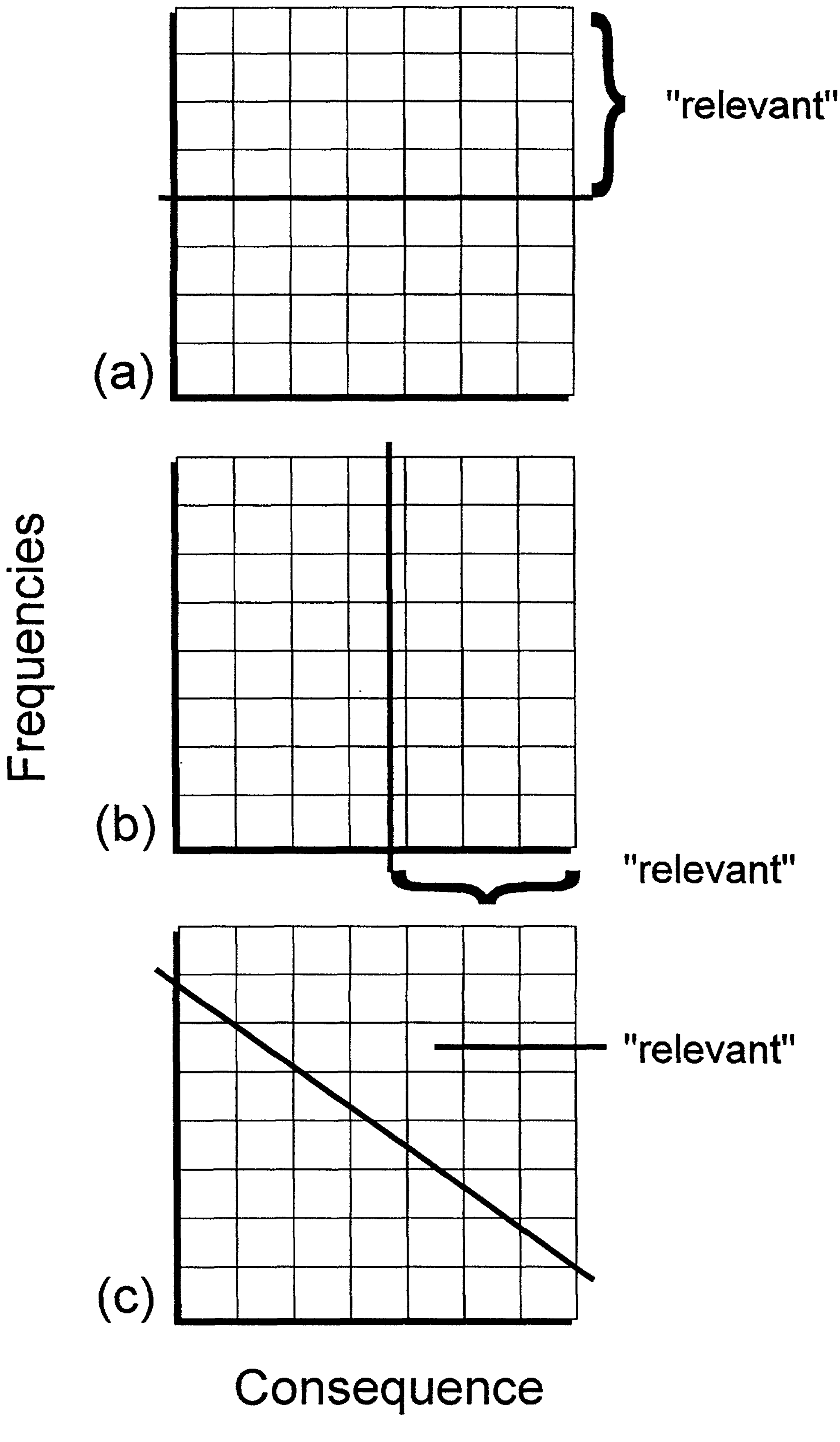


FIG. 10. Options for the acceptability criteria for societal risk.

8. PRIORITIZATION OF RISKS

With reference to Fig. 9, the priority assessment risk categories correspond to the upper right hand side of the matrix of probability versus 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, with smaller frequency, are perceived as more important than those of smaller consequences with higher probabilities.

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

- by setting a threshold for the probability class only (Fig. 10 (a)); or,

- by setting a threshold for the class of consequence only (Fig. 10 (b)); or,

- by considering a combination of both classes (Fig. 10 (c)).

8.1. PROCEDURAL STEPS

■ Identify on the matrix of frequency versus consequence all the activities which do not meet the selected criteria (i.e. all the activities whose calculated risk is beyond acceptability).

■ The list of all these activities is the final product.

9. NOTE ON IMPLEMENTATION

It is not within the scope of the manual to recommend any particular criterion for risk acceptability or tolerability. The following guidance may be of help.

■ The matrix allows the user to differentiate between fixed installations and (parts of) transport routes;

■ Activities are scattered throughout the consequence versus probability matrix enabling classification and prioritization;

■ In section 8 a general idea on how this could be established is given;

■ Be aware of (lack of) information given by the figures in the matrix.

- The figures found by using the manual are only characteristic for the probability and the consequences of an accident. More serious accidents could happen, although with a lower probability. Less, but still serious accidents are possible in a wide range, normally with a higher probability. The ranges depend on the kind of activity and the substances involved (the vulnerability of the neighbourhood is of course constant for a given activity). A rough guidance, in order of magnitude and apart from the limited value of some parts of the risk analysis techniques is given in Table XXI.

TABLE XXI. DEVIATIONS IN RESULTS

Per accident	More serious consequences although lower probability		Less serious consequences although higher probability	
	Conseq	Prob	Conseq	Prob
Flammables	Half[a]	Half	Half	One
Toxics	One	One	One	Two

[a] Orders of magnitude.

These kinds of estimations are based on typical risk curves involving flammables or toxics:

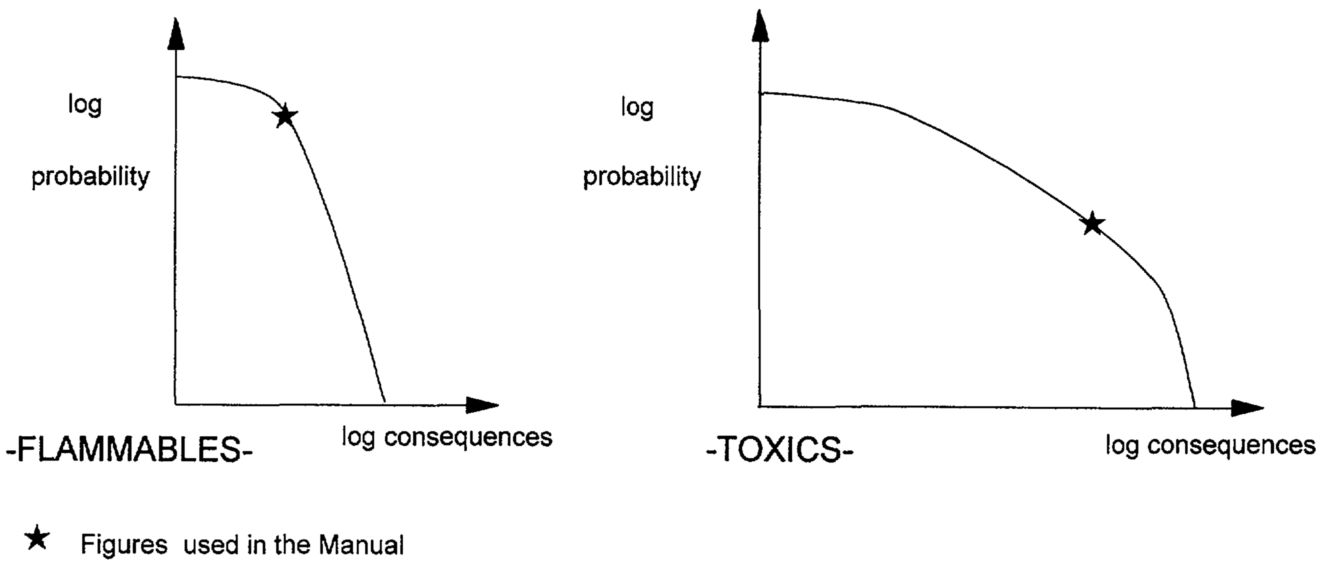


FIG. 11. Typical societal risk curves for flammables and toxics.

- Apart from figures of lethality, more people could be injured. In the case of flammables half an order to one order of magnitude; in the case of toxics two to three orders of magnitude (which depends on the substance involved).

- The figures give no information about environmental damage which could be the case especially with accidents near or on water.

- The figures do not include differences in emergency planning although it must be noted that most of the consequences of the type of accidents that have been calculated in the Manual take place in less than one hour which give limited opportunities for repression additionally to the mitigation factors that have already been included in the Manual.

■ The user decides where to draw the line. In the case of emergency planning purposes (main question: what could happen) high consequences are of more importance than probabilities. In the case of prevention both, consequences and probability are important. In general, given the aversion of society against "disasters", "calamities", there is more attention on the consequences. Still, investments to avoid high consequences (but with low probabilities) could be very high. Also measures and physical planning are limited in most countries using risk assessment by threshold probability figures.

Only to give the user an idea how to deal with risk figures:

- per activity the probability of fire is in the order of magnitude of 10^{-3} per year, which in general is reason to decide on a specific fire brigade for the plant.

- in some countries (UK, Netherlands, Australia) figures of more than 10^{-6} per year are relevant for external safety policy (i.e. the risks for residential areas)

- in the mentioned countries at least a lot of attention - the ultimate measure is to avoid the riskful situation - is given to the possibility of consequences with thousand or more people involved (killed or injured)

- one should use the figures of industrial activities in perspective with other possible disasters: of natural origin (earthquakes, inundation, hurricanes etc.) and "others" (failures of water supply systems, traffic accidents, airplane crashes, and ferries).

Some of the disasters mentioned here could be of more importance than those the manual is used for. Some of them are more or less unavoidable. Others, take for instance a crowded airport, should be part of the discussion of how to deal with risks too.

Appendix I

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

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 Dimethilcyclohexane 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

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 Carbon monoxide Cyclobutane Cyclopropane Difluoroethane Dimethyl ether Ethane Ethyl chloride Ethylene oxide Ethyl fluoride Isobutane Isobutylene LPG Methyl ether Methyl fluoride Propadiene Propane Propylene Vinyl chloride Vinyl methyl ether Vinyl fluoride
10, 11	Flammable gas liquefied by cooling (See also list of flammable gases liquefied by pressure (reference numbers 7–9)	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

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

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 Formaldehyde solutions Hydrofluoric acid Isobutylamine Methylchloroformate Methyldichlorosilane Methyl iodide Methyltrichlorosilane Nitric acid (fuming) Oleum (fuming sulphuric acid) Propylene imine Propylene oxide Tin tetrachloride
22, 25	Toxic liquid high	Hydrogen cyanide Nitrogen dioxide Sulphur trioxide Tetra-butylamine
26, 29	Toxic liquid very high	Methyl isocyanate Nickel carbonyl Pentaborane 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 Fluorine Hydrogen fluoride Methyl biomide Nitrogen trifluoride Perchloryl fluoride Silane Silicon tetrafluoride Sulphur dioxide Trimethylamine Vinyl bromide

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

For a substance not listed in the above table, the toxicity class can be determined by applying the following general rules:

(a) Consider as liquid if vapour pressure < 1 bar at 20°C;
(b) Consider as gas if vapour pressure > 1 bar at 20°C;
(c) Sum the calculation numbers a and b derived from the LC_{50} and physical properties tables below and compare with the following:

LC_{50} rat 4h in ppm	Calculation number (a)
0.01–0.1	8
0.1–1	7
1–10	6
10–100	5
100–1000	4
1000–10 000	3
10 000–100 000	2

Physical properties		Calculation number (b)
Liquids	< 0.05 bar	1
(pressure at 20°C)	0.05–0.3 bar	2
	0.3–1 bar	3
liquefied gas compressed	> 265 K	3
boiling point	< 265 K	4
liquefied gas cooled	> 245 K	3
boiling point	< 245 K	4

Sum a + b	Toxicity class
6	Low
7	Medium
8	High
9	Very high
10	Extreme

Appendix II

ADDITIONAL BACKGROUND

The Manual for the Classification and Prioritization of Risks due to Major Accidents in Process and Related Industries is based on ideas which go back more than 10 years. All too often expensive and time consuming risk analyses have been carried out, without answering the questions: (a) Were the efforts applied to the most important industrial activities? (b) Were the efforts done with the view that the final result would be decision making to improve the situation?

The situation nowadays is that with increasing experience in the particular field of risk analyses, only a few hundred experts in the world are able to assess the need for a detailed analysis bearing in mind of course the need to reduce relatively high risks. With large inventory projects, which are necessary to get an overall view, this relatively small work force is in a difficult situation. Manuals such as this are written to help with this problem.

The Manual described here is based on a few (conflicting) objectives:

(1) The Manual had to be convenient for the user;
(2) The Manual had to take account of the diversity between the (risks of) industrial activities investigated;
(3) The Manual should cope with all kinds of industrial activities;
(4) The Manual had to be logical and scientific;
(5) The user should not need too much background information;
(6) The user had to decide which rates of importance should be given to the risks of the industrial activities.

It is clear that compromises have been made in writing this Manual. Comparing the results of the methods described in this Manual with results of a specific detailed risk analysis is like comparing a map of a scale of 1:200 000 with a map of a scale of 1:10 000. People still need both maps, only the objectives for using those maps are different and that is exactly the point to stress.

As mentioned before, writing a Manual like this can be done in a limited space. The main problem in writing the Manual is, however, how to combine the information available from detailed analyses, experience in the field and users of first generation manuals. Addressing this main problem and collecting data from studies which have been carried out before has taken years.

In the Netherlands, the quantitative risk approach for so-called chemical industrial activities started more than ten years ago. This approach is more strongly supported in the Netherlands than in most other countries. Issues such as individual risk and societal risks are openly discussed. More and more this approach is being used within the decision making process and political questions (measures to be taken, zoning, emergency planning, etc.). Detailed studies have been carried out starting with the integral LP6 study and the study of transporting ammonia and chlorine. By implementing the so-called post-Seveso Directive of the EC, detailed risk analyses of very different industrial activities have been carried out. Furthermore, it was already common practice to assess risks caused by accidents in the licence system. Last year developments were strongly focused on the risks caused by the transport of hazardous substances. Methods for assessing these risks have been developed. Most of them, like the present Manual, are for use as a first overall planning procedure.

The methods behind this Manual are based on professional experience and expert judgement. Basically most of the scientific knowledge, even many of the figures used, were available, although never summarized (in a step by step approach) in such a way.

PHILOSOPHY

A chain is only as strong as its weakest link. Risk assessment is like a chain of different models: models for assessing probabilities, models to calculate effects of certain chosen scenarios and models to describe the damage of a certain effect (e.g. probit functions for toxics). It is well known that even a very detailed risk analysis has to deal with uncertainties, for instance the probability of ignition, the influence of maintenance or the question of how to use data from experiments with rats (e.g. LC_{50} values).

Even such a detailed risk analysis has limitations by using it in an absolute way, however results like these are used because there is no other practical alternative available.

Appendix III

AN EXAMPLE WORKED OUT IN PRACTICE FROM "SUMMARY OF THE CASE STUDY ZAGREB PROJECT" PREPARED BY M Sc DEJAN SKANATA, HAZARDOUS WASTE MANAGEMENT AGENCY, MARCH 1995

In this appendix excerpts are taken from the above mentioned case study.

III.1. OBJECTIVES OF THE PROJECT IN ZAGREB

One of the main objectives of the Project was to introduce the integrated (holistic, area-wide) approach in dealing with the ecological problems in the Environmental Protection Policy in the City of Zagreb. This approach should be based on the Risk Assessment and Risk Management methodologies, while participation in the Inter-Agency Programme should support the realization of this objective and enable the Project team to apply gained experience and knowledge in the field to other industrial areas in the Republic of Croatia.

The aim of the Project is to assist, together with other similar activities undertaken within the existing Environmental Policy Plan for the City of Zagreb, in defining the optimum method of risk management in the area, to improve the level of know-how in the field, to enhance the ability of relevant institutions to react in an appropriate fashion in the event of various kinds of accidents in energy plants and other complex industrial installations. A further aim of the Project is to assist in the industrial development of Zagreb with maximum control and risk management linked with such development. The expected direct results of the Project are, among other things, as follows:

- implementation of practical methods of risk management and the control of hazardous events and activities;
- improvement of policies in the field of protection of human health and environment;
- optimum streamlining of funds designed for the reduction of risks to which the population and environment of the City of Zagreb and Zagreb county are exposed; and
- active promotion of the integrated approach to Risk Management in the everyday practice with special emphasis on professional training.

III.2. RISK ASSESSMENT OF MAJOR INDUSTRIAL ACCIDENTS

One of the basic goals of the CSZ (Case Study Zagreb) Project was the health and environmental risk assessment of major industrial accidents which might occur on the fixed facilities in the City of Zagreb. It was for that purpose that the whole process of risk analysis and assessment was conducted in the four following phases:

1. Identification of dangerous facilities and hazardous activities and substances;
2. Risk assessment due to major industrial accidents based on the Rapid Risk Assessment (RRA) methodology[1] implementation developed within the Inter-Agency Programme and recommended to the Steering Committee of the Project by the IAEA;
3. Establishing the preliminary acceptance criteria of technological risks; and
4. Analysis of the current status in the field of organization and preparedness in case of industrial accidents in the City of Zagreb.

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[1]Manual for the Classification and Prioritization of Risks due to Major Accidents in Process and Related Industries, IAEA-UNEP-UNIDO-WHO, IAEA-TECDOC-727, Vienna, December 1993.

FIG. 12. Industrial zones and larger industrial sites in the City of Zagreb.

In order to collect information about possible risk sources from stationary industrial facilities, during 1992 and 1993, a survey among 265 relevant industrial and trade companies in the City of Zagreb was conducted. For the purpose of organizing the collection, and later on the data processing, a special database with associated applications for data searching, sorting, changing, completion and deletion was developed. A complete software package was organized in two modules (HAZIN and HAZOUT) and adapted for the use on PC hardware configuration. Altogether 197 companies participated in the survey and filled in the questionnaire. This made the survey 74% formally successful. Nonetheless, according to the engineers' judgement and experience, the survey was found 90% successful. This optimistic assessment is based on the fact that almost all industrial facilities which might become, in case of a severe accident, sources of substantial risk were covered by the survey and were thus included in further risk analysis. Figure 12 shows the arrangements of areas and separate locations (1-8) where the analysed industrial facilities are situated.

The above mentioned database has become the basis for the RRA methodology implementation which was used to obtain a preliminary, i.e. general quantitative overview of risks from various industrial facilities in order to identify the priorities for further detailed risk and safety analyses and to define activities which should be undertaken for the purpose of risk reduction. In order to specify these priorities in the Case Study Zagreb (CSZ) Project the preliminary acceptability criteria for the societal risks from technological facilities were introduced. As an upper acceptability threshold of a societal risk for maximum 10 fatalities per accident, the value of 10^{-4}/year is accepted, while the value for a threshold of a negligible societal risk under the same conditions is 10^{-6}/year. The area between these two values is called the risk reduction area. The n-n^2 rule, saying that if the number of fatalities in a possible accident is increased by n times at the same time, the probability of an accident should be reduced by n^2 times, was used for other values of societal risk.

III.3. RESULTS

The results obtained by the RRA methodology (symbols) together with preliminary risk acceptability criteria (straight lines) have been illustrated in a co-ordinate system of probability, i.e. frequency versus possible consequences of an accident (F-N curve) in order to determine priorities for further analyses (Fig. 13). Adoption and application of the RRA methodology together with the preliminary acceptability criteria of the technological risks showed that only 2.5% of the total number of surveyed companies falls within the unacceptable risk area, so they were considered a main priority for further activities in applying an integral and consistent system of technological risk management. The next 5% of the total number of surveyed companies fell within the risk reduction area, so they represent the second group of priorities (Table XXII). The obtained results show that a relatively small number of dangerous technologies (located mainly within two industrial zones in the City of Zagreb) require further detailed risk analysis and possible risk reduction. This is assessed as a direct consequence of a relatively good spatial distribution of dangerous technologies. Yet, the obtained results can be used for relative comparison of risks, but cannot be taken for absolute assessment or management of risks for individual facilities. Also, it was assessed that the RRA methodology represents a very useful tool for the first step in establishing a systematic and consistent area-wide approach of the Risk Assessment and Risk Management System.

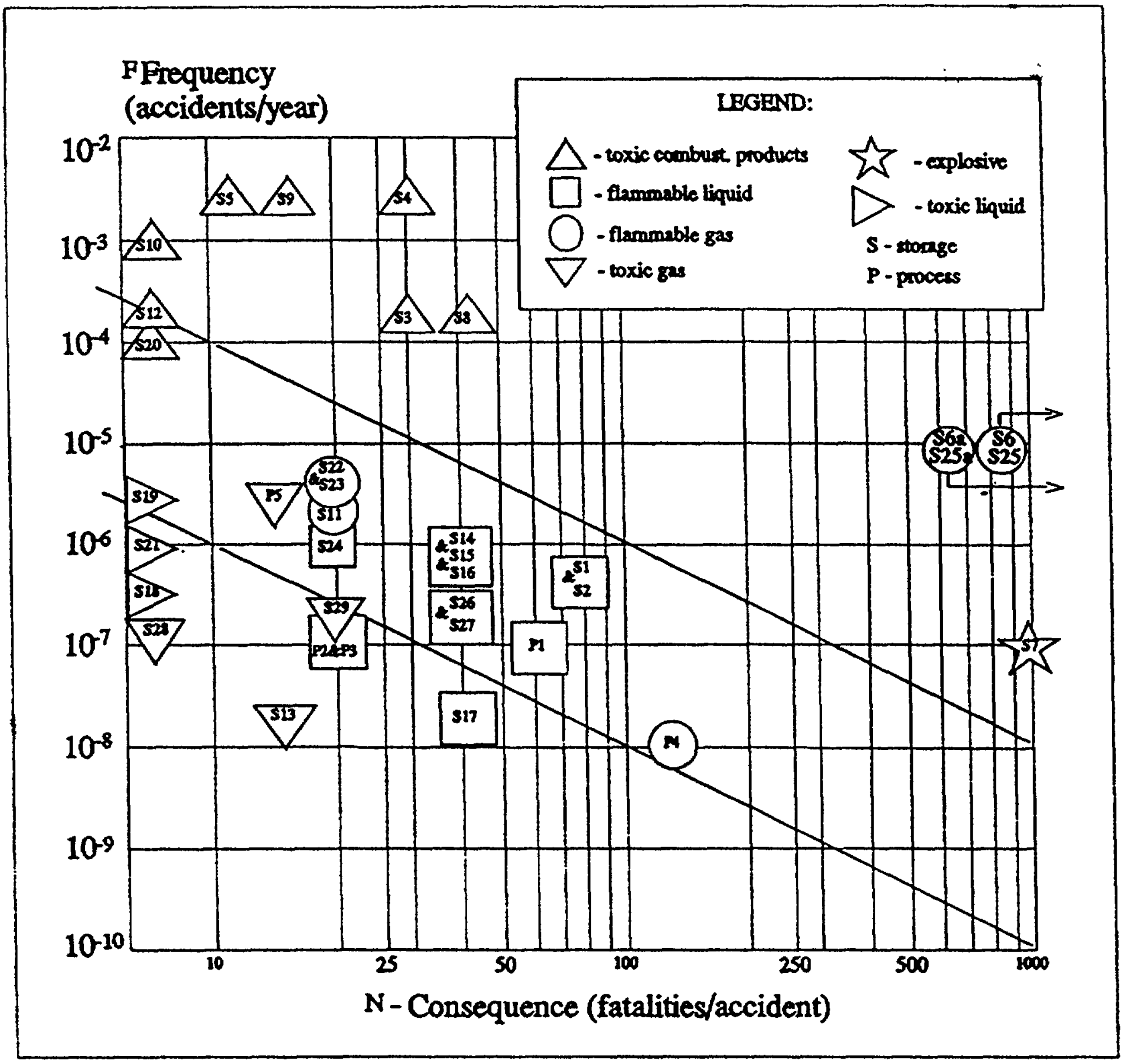

FIG. 13. Graphical presentation of RRA results (F–N curve).

TABLE XXII. REVIEW OF RISK PRIORITIES FOR FURTHER ANALYSES

Number of facilities	Type of facility	Type of hazardous substance	Name of hazardous substance
UNACCEPTABLE RISK AREA (Priority 1)			
6	Storage	Toxic combustion gases	Pesticides, polymers, fertilizers
2	Storage (tanks)	Flammable gases	LPG
1	Storage	Explosive substances	Urea nitrate
RISK REDUCTION AREA (Priority 2)			
2	Storage	Toxic combustion gases	Pesticides, insecticides, polymers
3	Storage (tanks)	Flammable gases	LPG, butane, propane
8	Storage (tanks)	Flammable liquids	Organic solvents, petrol, diesel oil, oil
1	Storage (tank)	Toxic liquid	Nitric acid (fuming)
1	Process	Flammable liquid	Acetone
1	Process	Toxic gas	Chlorine
1	Process	Flammable gas	Propane

As regards the organization and preparedness of the system to react in case of industrial accidents involving possible effects on the inhabitants of the Zagreb area, the following two general conclusions can be made:

1. In the area of Zagreb, the largest industrial centre and the capital of Croatia, there are potentials and means organized on partial and sectoral basis in case of industrial accidents. However, there is no integral, interconnected, trained and verified system for these needs and no solution for the organization and financing in order to maintain permanent preparedness and capability of reacting. The situation is somewhat better with preventive actions (inspection services).

2. Presently, the legislation in this field is being developed and adapted so as to comply with the international conventions and practice. Therefore, it could be said that presently the rescuing system in case of an accident in the City of Zagreb has not been developed yet. There are neither adequate plans nor connections with databases on hazardous substances, in particular with the facilities of the chemical industry, and with social welfare facilities such as hospitals, children institutions, schools, old people homes, etc.

All the mentioned considerations taken together, it is clear that the APELL[2] process should be implemented in the Zagreb area as soon as possible. The same conclusion can be drawn from the results achieved by the application of the RRA methodology. Although the assessed frequency values for large industrial accidents involving numerous fatalities are of the order of magnitude of $10^{-5}-10^{-7}$ per year (which represent a relatively low probability), the possible number of victims (from some hundreds to some thousands) requires immediate improvement of the organization and qualification of professionals for intervention in case of a chemical accident.

Within this activity the risk of the Krško NPP normal operation for the population of the Zagreb area was analysed and assessed. The impact of the Krško NPP normal operation was analysed by taking into consideration the radiological and thermal effects of the past operation and by making an assessment of the possible future impact of its operation. For this purpose the measurement data from authorized Croatian and Slovenian institutions[3] were used.

In order to assess the predictive effect of the Krško NPP further operation, an extrapolation of radiological monitoring data was performed for the area around the Krško NPP. The conservative approach, taking into account the distance between Zagreb and the Krško NPP (38 km air distance, SE), different weather conditions (Pasquill meteorological types, stability class C), dispersion of gaseous radioactive effluents (simple Gaussian model), and an estimate of the dilution factor, was applied. This has led to an assessment that the effective dose to an individual in Zagreb during the Krško NPP normal operation had an average value of 1.4 Sv/year. By making the comparison with the effective dose of the background radiation exposure, which an individual in Zagreb cannot avoid and which is about 1.22 mSv/year, it was noticed that the effects of the Krško NPP operation to the population of Zagreb are almost neglible. Consequently, the individual mortality risk[4] of the Krško NPP normal operation to the population of Zagreb area was estimated as 7×10^{-8}/year.

Additionally, the existing situation related to the plan of emergency actions to be taken in case of a serious accident in the Krško NPP was analysed. It was concluded that the already initiated actions in this field should be united in order to have, within the shortest possible time, on the basis of existing documents[5] and coordinated by the Ministry of Economy (Department of Energy)[6], a revised and satisfactory Operational Plan in case of a severe accident in the Krško NPP.

III.4. RECOMMENDATIONS

Table XXIII gives a summary of the recommendations formulated on the basis of the present study.

---

[2]Awareness and Preparedness for Emergencies at Local Level.

[3]Radiological monitoring was performed by the following institutions: "Jožef Štefan" Institute, Ljubljana; Institute for Safety at Work of Republic of Slovenia, Ljubljana; Institute of Medical Research and Occupational Health - University of Zagreb, Zagreb; and "Ruđer Bošković" Institute, Zagreb.

[4]In accordance with ICRP Publication No. 60, 1990 Recommendation of the ICRP, Oxford, Pergamon Press, 1990, the value of 5×10^{-2}/Sv was taken as the conversion factor of radiation risk.

[5]"Plan of Emergency Actions in the Case of an Accident in the Krško NPP", the Republic Secretariat of Energy, Industry Mining and Handicraft Trades, Zagreb 1981, and the Draft "Plan and Programme for Protection from the Harmful Effects of the Ionizing Radiation and Radioactive Contamination of Territory of the Republic of Croatia, Zagreb 1991.

[6]There is a Project entitled: "Development of Infrastructure for Radiation Protection and Nuclear Safety in the Republic of Croatia" - CRO/9/002-01, Item 6 - Emergency Preparedness Based on an Analysis of Hypothetical Accidents and a Study of Radiological Consequences of these Accidents; Medical Aspects of Nuclear Accidents; which is managed by the Ministry of Economy (Department of Energy) in co-operation with the IAEA.

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TABLE XIII. RECOMMENDATIONS FOR RISK ASSESSMENT OF MAJOR INDUSTRIAL ACCIDENTS

Field of application	Recommendations
Hazard identification	1. Ensure systematic improvement and updating of database on dangerous substances and activities established within the Project. 2. Supplement the existing or create a new database containing data on the transportation of hazardous substances.
Risk assessment of industrial accidents	1. Provide additional insight into the safety status of those facilities and storages which have been identified by RRA methodology as potentially significant risk sources for public health and environment (priorities 1 and 2); prepare detailed safety and risk studies for them. 2. Apply RRA methodology for risk assessment in transportation of hazardous substances. 3. Apply knowledge gained in this field to other industrial environments in the Republic of Croatia.
Acceptability criteria of technological risks	1. Discuss in more detail and, within the environmental protection regulation, adopt values for socially acceptable risks.
Level of organization and preparedness in cases of industrial accidents	1. Organize an integral and consistent system of action in all kinds of emergencies. In that sense, apply APELL concept as soon as possible, i.e. make arrangements and provide finances for permanent maintaining of the Awareness and Preparedness System. 2. Start with the project of creating a database about industrial accidents occurred both in the City of Zagreb and the Republic of Croatia. In this way participation in and access to EU database (FACTS, MHIDAS and other databases) will be made possible.
Krško NPP	1. Continue with all those activities which, in accordance with international recommendations, contribute to increased safety and reliability of Krško NPP operation. 2. Combine the initiatives already started to prepare an action plan in case of accident at Krško NPP.