EUROPEAN COMMISSION
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Benchmark Exercise in Quantitative Area Risk Assessment in Central and Eastern European Countries (BEQUAR)

Final Report

by Luciano Fabbri, Pavel Jirsa and Sergio Contini

Institute for the Protection and Security of the Citizen

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TABLE OF CONTENTS

DESCRIPTION OF THE BENCHMARK EXERCISE IN QUANTITATIVE AREA RISK ASSESSMENT 5

1. Background 5
2. Project Objective 6
3. Scope 6
4. ARIPAR Methodology 7
5. Work Programme 7
   5.1 Documentation phase 7
   5.2 Working phase I (Review of the risk analysis data) 8
   5.3 Working phase II (Comparison of the different reviews and Area Risk Assessment) 9
6. Funding and Participation 9

GENERAL DESCRIPTION OF THE REFERENCE ESTABLISHMENT 11

1. Background 11
2. Impact Area 11
3. Dangerous substances 12
4. Main Installations considered for the risk Analysis 13
   4.1 Sulphur Dioxide: unloading station (N. 106) 14
   4.2 Storage of Ethanol 15
5. Hazard identification analysis and Scenarios' identification 15
6. Visit to the Reference plant 16

REVIEW OF THE SCREENING METHOD AND OF THE HAZARD IDENTIFICATION ANALYSIS 17

1. Introduction 17
2. Review method 17
3. Review of the 'Screening method' 18
4. Review of the Hazard Identification Analysis 19
   4.1 General 19
   4.2 Review Scenario by Scenario 21
5. Summary of the hazard identification analysis review 32

REVIEW OF THE FREQUENCY DATA 36

1. Introduction 36
2. Summary of Frequency Data 36
3. Review of frequency data Scenario by Scenario 39
   3.1 SO_2 related Scenarios 39
   3.2 Ethanol related Scenarios 51

REVIEW OF THE CONSEQUENCE ASSESSMENT 53

1. Introduction 53
2. Summary of the results of Consequence analysis 53
   2.1 Source Term' results: SO_2 related Scenarios 53
   2.2 Source Terms' results: Ethanol related Scenarios 56
   2.3 Vulnerability data 58
3. Review of the source terms' data 60
   3.1 Reaction and repair time 60
   3.2 Source terms 61
4. Review of the vulnerability data 63

4.1 Summary of the vulnerability analysis review 65
REVIEW OF THE ANALYSIS OF RISKS AND AREA RISK ANALYSIS 67
1. Introduction 67
2. Summary of the results of the risk of the reference Plant 67
2.1 Methodology 67
2.2 Input data 69
2.3 Risk calculation for selected sources 72
3. Risk Analysis Review 76
3.1 General 76
3.2 Scenario by Scenario analysis 86
3.3 Summary of risk analysis review 95
CONCLUSIONS 97
General Remarks 97
Hazard Identification Analysis 97
Frequency Data Review 98
Consequence Assessment Review 99
Risk Analysis Review 100
Final Remarks 101
ACKNOWLEDGMENTS 103
APPENDIX I (HAZOP) I
1. Sulphur dioxide ii
2. Ethanol Storage vi

DESCRIPTION OF THE BENCHMARK EXERCISE IN QUANTITATIVE AREA RISK ASSESSMENT

1. BACKGROUND

The JRC enlargement project, "Management of Natural and Technological Hazards" (Project PA No. 26: http://www.jrc.cec.eu.int/enlargement/jrc-projects.htm), was launched during the Fifth Framework Programme, with the main objective of providing technical support to the EU Candidates Countries for the management of risk associated with natural and technological hazards, particularly in the area of data collection and information management systems. The project final report was published as a EUR document (EUR 20834 EN[1]). As a follow up to this activity, a strategy for future collaboration between the JRC and the Accession and Candidate Countries within the Sixth Framework Programme has been established. This was fully discussed and agreed with Accession and Candidate Countries' participants in the Workshop on Collaborative Activities held in Ispra on 22-24 June 2003, where a detailed work programme was defined. The main focus was on data collection and analysis, information management systems and the development and application of risk assessment techniques in support to the management of natural and technological hazards. Amongst the specific topics identified during the Workshop, particular attention was given to the application of risk assessment techniques for the production of Safety Reports of Seveso II type establishments.

Previous European benchmark studies coordinated by the JRC [2,3] provided a clear overview of the state-of-the-art of the various practices, methodologies and tools used in the different EU countries in the process of risk analysis of chemical establishments. These studies demonstrated the degree of uncertainty in the different phases of the risk analysis process and identified some of the main causes. In order to better understand the risk analysis practices and methodologies adopted in the Accession and Candidate Countries, it was agreed to launch a third benchmark exercise focusing on the evaluation of the risk of a particular area in the proximity of a hazardous establishment. Since the group of this Collaborative Activity consists of representatives of the National Competent Authorities, it was decided to organise this benchmark from the point of view of a competent authority inspector. Thus, unlike the previous benchmark exercises, where a full risk analysis was conducted on a reference chemical establishment, it was decided that the participants should make an independent review of the results of an existing risk analysis study, conducted by the plant operator, from an inspector perspective.

The selected chemical establishment to be used as the reference plant for this benchmark was an actual lower tier Seveso II plant, which was highlighted by the Hungarian Competent Authority for the implementation of the Seveso II Directive (National Directorate General for Disaster Management). In order to ensure anonymity of the selected establishment, it was intentionally decided to modify the environmental setting in which the plant is located, the local vulnerability and the population density. This choice was driven by the necessity of avoiding that any outcome of the benchmark might be misinterpreted in terms of the actual risks associated with the territory where the reference plant is located.
The reference risk analysis submitted to review was based on the risk analysis extracted from the existing safety report of the actual reference establishment. However some of the original

1 M. Wood, A. Vetere Arellano, F. Mushtaq, " Management of Natural and Technological Hazards in Central and Eastern European Countries (PECO)", EUR 20834 EN

2 A. Amendola, S. Contini, I. Ziomas, "Uncertainties in chemical risk assessment: results of a European benchmark exercise", the Journal of Hazardous Materials. 29 (1992) 347-363

3 K. Lauridsen, M. Christou, A. Amendola, F. Markert, I. Kozine, M.Fiori: "Assessing the Uncertainties in the Process of Risk Analysis of Chemical Establishments: Part I & II", ESREL 2001, E.Zio, M.Demichela and N.Piccinini (eds.), Vol.1 pp.592-606

data, assumptions and calculations were suitably modified by the JRC with the main intention of making this analysis uncorrelated from the actual case. For this reason, it is possible to state unambiguously the non addressability of the conclusions of this study to the actual plant used as the reference plant. A point to note is that, such a re-elaboration of the original risk analysis to produce a consistent reference risk analysis would not have been possible without the assistance and the close co-operation with the consultant company, which produced the original safety report (CK-Trikolor Kft). This assistance was requested by the Hungarian Competent Authority, and was essential for the understanding of the risk assessment methodology that was used in the present case.

To improve the inter-comparability of the results it was decided to select a single tool to present the risk analysis results. This is based on the ARIPAR methodology[4], which provides also a powerful tool for evaluating the risk of a particular area in the proximity of a hazardous establishment arising from different risk sources. The use of ARIPAR provided a good example of a quantitative Area Risk Assessment application, which is essential to support any decision-making process involving the impact analysis of risk resulting from different sources, and the elaboration of alternative solutions for risk reduction.

2. PROJECT OBJECTIVE

The project activity consisted of a benchmark exercise for evaluating the risk of a hazardous establishment and the area risk resulting from it by using the ARIPAR 4.0 software package. More specifically the main objectives were as follows:

- to conduct independent reviews by the different national teams of the reference risk analysis of a particular hazardous establishment (or part of it), as re-elaborated from the original safety report of the plant;
- to assess the risk in the selected impact area.

The main intention was to offer a general perspective on how independent reviews of the same risk analysis study, which are conducted from the competent authority's standpoint, might differ form each other and be reflected in a different evaluation of the risk of a certain Seveso type establishment. The outcome of such an analysis has the evident advantage of contributing towards better understanding the inspection criteria and current practices used by the different national authorities.

In addition, the study was also intended to provide a practical exercise of area risk assessment to assess the impact of an industrial site on the overall area affected by potential accidents and a first attempt to analyse how different reviews/interpretations of a specific risk study might be reflected in the estimate of area risk.

A clear spin-off of this activity was the creation of a discussion platform about the current practices and approaches in the different represented Member States to evaluate the several aspects of a risk study for a Seveso-type establishment.

3. SCOPE

The benchmark was conducted on an industrial establishment existing in one of the countries participating in the exercise (Hungary).

The selected establishment was a lower tier Seveso II plant (i.e. falling under Article 9 of the Seveso II Directive), thus ensuring that the facilities, systems and components and the

4 G.Spadoni, D. Egidi, S. Contini, "Through ARIPAR-GIS the quantified risk analysis supports land use planning activities", Journal of Hazardous Material 71 (2000) 423-437

associated risks under investigation be realistic. In order to ensure anonymity of the selected establishment, it was intentionally decided to modify the environmental setting in which the plant is located, the local vulnerability and the population density. In this way it was possible to avoid that any outcome of the benchmark might be misinterpreted in terms of the actual risks associated with the territory where the reference plant is really located.

4. ARIPAR METHODOLOGY

ARIPAR is a quantitative area risk assessment tool used to evaluate the risk resulting from major accidents in industrial areas where hazardous substances are stored, processed and transported. It is based on a geographical information system platform (GIS). The application of this tool requires the quantification in terms of frequency and consequence of all significant accident Scenarios - identified by means of systematic techniques, e.g. Hazop and FMEA – in fixed installations and for the transport of dangerous substances.

ARIPAR is based on a set of procedures designed to determine, through the combination of the occurrence frequency of postulated accidents and the associated consequences (i.e. causalities), the local, individual risk and societal risk. Specifically the main phases of the ARIPAR risk analysis procedure can be summarised as follows:

- Definition of the “impact area” and collection of all relevant territorial data (population density and distribution, vulnerability centres, meteorological data, transport).
- Identification of industrial and transport activities involving dangerous substances and definition of all significant risk sources, which could affect the considered impact area.
- Identification of potential accident Scenarios for all risk sources (toxic releases, fires and explosions). Assessment of their frequencies and consequences.
- Calculation of the overall risk, which accounts of the possible non-symmetrical distribution of risk around the different risk sources.

The ARIPAR methodology has already been applied to perform a quantitative assessment of the risks connected with processing, storage and transportation of dangerous substances in several industrial areas, and it has been demonstrated to be a very powerful tool also for managing industrial risk. Given the strong interest expressed by the representatives of Candidate and Accession Countries participating in this mutual collaboration programme, the JRC decided to translate the ARIPAR software package in English for its general use and distributed the resulting release (ARIPAR 3.0) to all the members in October 2002. Meanwhile a new and more advanced version of ARIPAR was developed (ARIPAR 4.0), which was distributed amongst the BEQUAR participants. In addition and in conjunction with this activity, a series of training modules were also organised for the participants in this benchmark.

5. WORK PROGRAMME

The project was structured in three main phases: a documentation phase and two working phases.

5.1 Documentation phase

The JRC together with the representative of the Country selected to provide the reference establishment, collected all relevant information on the involved installations. They produced an internal document that was distributed to the other members participating in the benchmark exercise[5].

This document contained:

[5] Internal Document: BEQUAR RP Rev 1.0, Technical Note, April 2004

Territorial data
- Topographic map of the hypothetical site.
- Information on the meteorological conditions and atmospheric stability.
- Population density.
- Vulnerability data.

Establishment data
- Detailed description of the installations.
- Layout diagrams.
- Process and Instrumentation Diagrams (P&DI).

Risk analysis data
- Hazard Identification Analysis.
- Frequencies of accident Scenarios (with information on existing mitigation measures and devices and related reliability and availability).
- Damage profiles for each accident Scenario.

The risk analysis data such as frequencies of initiating events, reliability/availability of safety measures, damage curves and *probit* functions were extracted from the original safety report of the reference establishment. They were then suitably modified and/or recalculated and, afterwards, distributed to the BEQUAR participants.

After having examined the documentation the members were invited to a specific meeting organised by JRC and Hungarian Competent authority at the premises of the reference establishment in order to visit its installations and to better understand the processes involved. The possibility to ask specific questions to the plant operator was also given. Afterwards, questions and related answers were collected and circulated amongst all the members in order to assure uniform information about the reference installations.

All relevant data extracted from the produced documentation were uploaded on ARIPAR and distributed to the members.

5.2 Working phase I (Review of the risk analysis data)

This second phase started with the definition of the main criteria for organising the review activity of the different BEQUAR members. Specifically their review, which were supposed to be totally independent from each other, focussed on:

- Analysis of the postulated accidental Scenarios.
- Frequencies of accident Scenarios.
- Accident consequences.

All the above elements are used as the input parameters for ARIPAR. The different teams made their review according to their own experience, methodologies and tools and they were given the possibility to introduce the modified data directly within ARIPAR. For instance, they could eliminate accidental Scenarios, which they would consider as not relevant, or introduce new ones, which they would judge as not taken into the right consideration by the operator. They were also allowed to modify frequency and vulnerability data, considered as not sufficiently conservative or inappropriate to the current situation.

A point to note is that, due to the limited resources, it was decided to limit the review of the consequence analysis by focussing on the source terms and the vulnerability data (probit values & threshold limits). The consequence damage profiles were, therefore, excluded from the review process.

5.3 Working phase II (Comparison of the different reviews and Area Risk Assessment)

The JRC team made a comparison of the outcomes of the different reviews conducted by the participants. This analysis was particularly important in order to:

- compare the different approaches adopted for assessing a risk analysis (databases, methods, procedures, models),
- study the variability of the review outcome obtained by independent teams, with different national cultures,
- study how some parameters (Scenarios, frequency or consequence outcome) can affect the area risk assessment (sensitivity analysis),
- identify possible areas for improvement.

- The results were examined during the several project meetings of BEQUAR.

For confidentiality reasons, the selected establishment and its installations were kept secret. A secrecy agreement was by signed all participating organisations, which provided detailed information on all obligations and rights.

6. FUNDING AND PARTICIPATION

The BEQUAR activity was funded under the JRC Enlargement and Integration Action which aims at providing scientific and technological support for promoting integration of the New Member States (NMS) and assisting the Candidate Countries (CCs) on their way towards their accession to the European Union.

JRC support for the CCs and NMS includes developing a pan-European science and technology reference system, a special focus on the transfer of the ‘acquis communautaire’ (the body of EU legislation and standards being implemented and monitored by the JRC), and contributing to the cohesiveness of the accession and integration process.

The JRC has covered the travel and subsistence expenses for all invited experts who participated in the BEQUAR activity in accordance with the European Commission rules. On the other hand the invited experts provided their contribution in kind for all those activities related to the review of the risk analysis of the reference establishment.

The following list provides the invited experts who actively participated in the benchmark exercise, with their affiliations:

Bulgaria
Tconka Dryankova, Ministry of Environment and Water.

Cyprus
Themistoclis Kyriacou, Department of Labour Inspection.

Hungary
Sándor Czakó, CK-Trikolor
Lajos Kátai-Urbán/Zoltan Czeplo, National Directorate General for Disaster Management – Ministry of the Interior.

Latvia
Maigurs Ludbarzs, Strategy Division of Civil Protection Department.

Lithuania
Vytis Kopustinskas, Lithuanian Energy Institute.
Petras Voveris/Ausra Sablinskiene, Fire and rescue Department, Ministry of the Interior.

Poland
Adam Markowski, Technical University of Lodz.
Andrzej Furtek, Centre of excellence MANHAZ (Management of Health and Environmental Hazards).

Romania
Alxandru Ozunu/ Septimius Mara, University of Cluj-Napoca.

Slovenia
Jasmina Kasba, Ministry of Environment, Spatial Planning and Energy.
Jernej Per, Slovenian Environmental Agency-EIA Department.

Slovakia
Magita Galkova, Environmental Agency.

GENERAL DESCRIPTION OF THE REFERENCE ESTABLISHMENT

1. BACKGROUND

The industrial establishment used as the reference plant for this benchmark belongs to an existing international food-processing company, which produces starch, dextrose, glucose syrups, isosugars, alcohol, and feed products by using maize as main raw material. To provide with a general idea of the activity involved, the plant capacity is of about 1200 tons corn processing per day. The plant possesses its own wells and produces drinking and process water on demand (5000 m^3 /day are currently in use). Most of the plant energy demand is provided by its own gas turbine.

The reference plant makes use and produces dangerous substances exceeding the qualifying quantity of Column 2 of Annex I of the Seveso II Directive. This determines the automatic application of Art. 6 and 7 (*low-tier establishment*). Specifically, the involved substances are: liquid *sulphur dioxide* used for the stepping process, and *ethanol* produced by the company and stored in several locations.

2. IMPACT AREA

As stated in the scope description of the BEQUAR project, the environmental setting of the reference plant was intentionally modified to ensure anonymity. In particular the exercise was conducted by assuming that the reference plant was located in a completely different location characterised by different local vulnerability, population density and distribution, and different weather conditions. In this way it was possible to assure that any outcome of the benchmark exercise might be misinterpreted in terms of the actual risks associated with the territory where the reference plant is located.

The hypothetical impact area is shown in figure 1. This area is an urban area very densely populated with flat terrain, which is located in the proximity of an Italian big city. Specific information on population distribution and presence was necessary for the following calculation of social risk information (FN-curves).

The reference establishment was fictionally located in this area in proximity of and artificial lake and is depicted in the centre of the figure. The critical installations of the reference plant were marked with red triangles.

Figure 1: Impact Area

3. DANGEROUS SUBSTANCES

The reference plant employs and produces dangerous substances in a quantity that makes it qualify as Seveso II low tier establishment. Specifically, the maximum quantities of these substances present on the site are listed in table 1.

Dangerous Substance	Max. Quantity (tons)	Seveso Cat.	Seveso II (96/82/EC)		Risk phrase	Aggregation state
			Art. 6 and 7 (column 2)	Art. 9 (column 3)		
Hydrochloric acid (32%)	232 (mixture) ca. 74.2 HCl	*2**	/	/	34-37	Liquid
Sulphur dioxide	**60**	2	**50**	200	23-34	Liquid
Ammonium-hydroxide (25%)	70 ca 17.5 NH_4OH	*2**	/	/	34-50	Liquid
Chlorine (in vessels)	0,2	0, 2, 9i	10	25	23-36/37/38-50	Gas
Ethanol (96%)	**9436**	7b	**5.000**	50.000	11	Liquid
Oxygen	11,4 (10 m^3)	0, 3	200	2000	8	Liquid

* *This substance is generally not considered as a Seveso classified substance due to the limited content of the dangerous substance in the mixture (HCl 32% and Ammonia 25%) It was conservatively classified as category 2 by the operator.*

Table 1: List of Dangerous Substances in the Reference Plant

In the table, for each substance, it was also indicated the associated risk phrase, the qualifying thresholds according to the Seveso Directive, and its Seveso Category as reported in the ClassLab Database (http://ecb.jrc.it/classification-labelling/). The specific meaning of the of the risk phrases and Seveso categories appearing in table 2 is illustrated in table 3.

Seveso Category
0 Named substance
1 Very Toxic
2 Toxic
3 Oxidising
7b Highly Flammable Liquids (Note 3b2)
9i Very toxic to aquatic organisms

Risk Phrases
R8: Contact with combustible material may cause fire
R 11 Highly flammable
R 23 Toxic by inhalation
R 34 Causes burns
R 37 Irritating to respiratory system
R 36/37/38 Irritating to eyes, respiratory system and skin
R 50 Very toxic to aquatic organisms

Table 2: Risk phrases and Seveso Categories as taken from the ClassLab Database

As previously stated, the presence of dangerous substances in a quantity that exceeds the qualifying threshold reported in column 2 of annex I of the Seveso II Directive, certainly qualifies the plant a Seveso lower tier establishment. The summation rule is then applied to determine the quantity present at the establishment and reported in tables 3 and 4, for toxics and flammables respectively. This calculation shows that the maximum quantity of dangerous substances present on the site never exceeds the upper tier threshold, which confirms the plant classification as a lower tier establishment.

Dangerous Substance	Quantity	q_x/Q (lower tier)	q_x/Q upper tier
Hydrochloric acid (32%)	232 t	74,2/50 = 1,48	74,2/200 = 0,371
Sulphur dioxide	60 t	60/50 = 1,2	60/200 = 0,3
Ammonium-hydroxide (25%)	70 t	17,5/50 = 0,35	17,5/200 = 0,085
	Sum for toxic	*>1*	<1

Table 3: Summation rule for toxics

Dangerous Substance	Quantity	q_x/Q (lower tier)	q_x/Q upper tier
Ethanol (96%)	11960 m^3	9436/5000 = 1,89	*negligible*
Oxygen	10 m^3	11,4/200 = 0,057	*negligible*
	Sum for flammable	*>1*	<1

Table 4: Summation rule for flammables

4. MAIN INSTALLATIONS CONSIDERED FOR THE RISK ANALYSIS

The installations considered as more critical for their potential off-site effects and therefore to be submitted to complete risk analysis were identified through one of the existing screening methods[6]. The establishment was conceptually split into a number of several installations, considered as 'independent' in case of accident occurrence. An indication number was calculated for each independent installation, which gives a measure of its intrinsic hazard, which depends on (*i*) the amount and type of dangerous substances present, (*ii*) the processing conditions and (*iii*) installation location.

For space reasons, the calculations are not reported in this document. However, by applying the criteria referred in the used guideline, amongst the several dangerous substances present on the site: Hydrochloric acid (32%), Ammonium hydroxide (25%) and Chlorine were not selected for the full QRA, whilst Sulphur Dioxide and Ethanol were considered for detailed

[6] Guidelines for quantitative risk assessment "Purple Book" CRP 18E

analysis. More specifically the installations that were selected for the analysis were as follows:

i. the tank wagon unloading station containing Sulphur Dioxide to be used for the stepping process, which in case of accident could lead to release of toxic substances in the environment (referred as N.106);
ii. the storages of ethanol, which in case of loss of containment could lead to fire and explosion. (tanks 1,2,3,10: area N.33 & tanks 6,7: area N. 34).

4.1 Sulphur Dioxide: unloading station (N. 106)

The unloading station is designed to allow the operation of the sulphur dioxide unloading process, from one tank wagon at the time. This station is characterised by a 15 meters long concrete platform with mesh screen for protection. Rail barriers are also installed in the front and back of the tank for safety reasons. These barriers stay at a distance of ca. 10 meters from the tank. During the wagon moving operation and fixing, no activities are permitted and entrance is not allowed within the station platform. Unloading can start only when the fixing operation is concluded.

The connection of the wagon tank to the inlet piping system of the plant is performed as follows:

- Put on the safety belt and connect to the fall prevention.
- Close the inlet pipe, and close the valve of the empty tank.
- Unbuckle the unloaded pipe-stub from the empty tank.
- Connect the inlet pipe to the unloaded pipe-stub of the full tank.
- Open the valve of the full tank.
- Make sure there is no any leaking.
- Open the inlet valve to the plant.

Preventing Actions

The control of the heating process and the execution of the sulphur dioxide unloading are performed by of the “steeping house operator” (two times every shift). The shift leader is responsible for this process and for the proper use of the safety equipments. Amongst the several controls which are executed during the unloading process:

- Visual inspection of possible SO_2 leakage in the surrounding of the unloading station.
- Proper fixing of the tank wagon.
- Condition of the unloading pipeline.
- Condition of the heating coil pipe.

All operations are recorded in a logbook, which is filled in by the shift operator who informs his shift-leader in case of any anomaly.

When unloading is terminated, the mechanic expert replaces the wagon tank. The steeping house operator has to control this activity.

The weigh of present sulphur dioxide is periodically measured (once per week) and registered on the logbook. As the rate consumption is well known (2 tons per day) a cross check can also be carried out.

The heating is performed by controlling the pressure. This is maintained to a fixed value of 0.5 bar during the whole operation.

Sensors
Eight sensors are used to detect possible leaks of SO_2. Six sensors are positioned around the tank wagon and two are placed on the top of the tank. The alarm system is set at 5 ppm and at 10 ppm and is transmitted to the control room.

4.2 Storage of Ethanol

The storage tanks containing ethanol, which were selected through the screening method mentioned in the previous section are located in the areas N. 33 and N. 34. These tanks are characterised by a different capacity volume.

The loading of the ethanol is continuous (12 hours) and the buffer capacity of intermediate storage tanks is 1 week. Automatic closure of the valve and stop of the pump is done in case of overflowing.

All tanks are characterised by level control equipments. The tanks are also fitted by fire protection. There is special water-cooling system on the top of the tanks to avoid over heating in summertime. That system reduces the losses from the evaporation of ethanol, which could occur through the vent holes.

All tanks are characterised by external bunds consisting of concrete walls, which are designed to contain all tank content in case of accidental release.

As ethanol storage and handling is associated to significant fire and explosion danger, the use of flame and smoking is forbidden in the whole plant area. Wood and other inflammable material cannot be stored in the plant.

5. HAZARD IDENTIFICATION ANALYSIS AND SCENARIOS' IDENTIFICATION

The Hazard Identification Analysis is a first and fundamental task within any process of risk analysis. This because the postulated accident Scenarios resulting from it strongly influence the whole risk analysis process.

The Hazard Identification Analysis has been conducted through a simplified HAZOP, and was officially presented to the BEQUAR participant at the kick-off meeting by the representative of the plant operator who was in charge of managing the HAZOP process. The full report is given in Appendix I where the accident Scenarios are also described.

The reference plant is characterised by quite simple processes and, in practice, the critical installations consist of storages of dangerous substances. For this reason the hazard identification analysis was relatively simple: standards guidewords were not used, and the whole set of parameters, which are typical of process operations of more complex systems, were not considered. Notwithstanding, the objective of the review of the hazard identification analysis is to assess whether all relevant accident Scenarios have been identified and properly described.

As previously outlined, the outcome of this hazard identification review is particularly important for the evaluation of the following aspects of the reference plant's risk analysis (i.e. frequencies and consequences) and for the estimate of area risk. However, this analysis is also interesting as a stand-alone process, by allowing the comparison of different approaches in different countries and from different perspectives, with regard to a specific application of hazard identification.

6. VISIT TO THE REFERENCE PLANT

A walkthrough visit to the Reference Plant took place in the morning of May the 17th, 2004, in conjunction with the kick-off meeting.. The main objective was to show to the BEQUAR participants the plant installations and the safety measures, which have been put in place. The focus was on those installations, which were identified by the plant operator as ‘critical’, though the risk screening method mentioned in the previous section. More specifically, the visited installations were the SO_2 unloading station (*area 106*) and the ethanol tanks (*areas 33 and 34*). All the visited installations are the ones associated to the accident Scenarios identified through the HAZOP.

The visit to the plant was also the first occasion for discussing about the identification of the main hazards and the postulated accident Scenarios. In particular, it took place a specific discussion on the HAZOP and the specific safeguards/protection measures indicated in the HAZOP, which were analysed by considering some schematic P&DI of the selected instillations.

REVIEW OF THE SCREENING METHOD AND OF THE HAZARD IDENTIFICATION ANALYSIS

1. INTRODUCTION

The first step of the benchmark consisted of reviewing the Hazard Identification Analysis the reference establishment with the intention of assessing the completeness and consistency of postulated accident Scenarios, the proposed protection measures and the adopted safeguards/ recommendations. This review was conducted by ten members of the BEQUAR group who played the role of an inspection authority. It is important to stress the heterogeneity of the BEQUAR group, consisting indeed of representatives of the Competent Authorities of the newly associated and candidate countries, as well as of experts of risk analysis working in research organisations. As a general recommendation it was advised to provide comments on the various aspects of the hazard identification process by using the proper experience as risk analyst, but also trying to provide some information on the position of the Competent Authorities in the proper country, with regard to the involved matters.

As previously outlined, being the reference plant characterised by quite simple processes, the hazard identification analysis was relatively simple: standards guidewords were not used, and the whole set of parameters, which are typical of process operations of more complex systems, were not considered. Notwithstanding, the objective of the review of the hazard identification analysis is to assess whether all relevant accident Scenarios have been identified and properly described.

A point to note is that outcome of this hazard identification review was particularly critical due to its potential effects on the following aspects of the reference plant's risk analysis (i.e. frequencies and consequences) and for the estimate of area risk. However, this analysis was also interesting as a stand-alone process, by allowing the comparison of different approaches in different countries and from different perspectives, with regard to a specific application of hazard identification.

2. REVIEW METHOD

In order to guide the review process and to facilitate the inter-comparability of the results it was decided to organise this exercise by making use of a review template, which was prepared by the JRC for this specific purpose[7]. The review template consisted of:

(i) a first section intended to allow the reviewers to perform a general assessment of the Hazard Identification Analysis as a whole, and

(ii) separate sections, which where introduced in order to explore the specific aspects of the different Scenarios. For most of the involved topics, the basic structure of the template was organised in term of multiple-choice questions.

This choice was driven by the necessity of setting up a system that allowed representing the general conclusions of the reviewers' group as a whole and in a subjective way. Free comments where also allowed in order to give the reviewers the possibility complement their answers.

Multiple-choice-questions were designed to measure the agreement of the responders about the involved topics. The possible choices ranged between the highest degree of agreement ("*totally agree*") to the lowest ("*totally disagree*") by passing through intermediate levels

[7] Internal report: BEQUAR HZP RVW TMPL Rev 1.1, Technical Note, June 2004

("*tend to agree*"and "*tend to disagree*"). The following scoring system was used for the analysis:

Answer	Score
Totally agree	4
Tend to agree	3
Tend to disagree	2
Totally disagree	1

In order to assess the general response of the BEQUAR reviewers on the involved issues, it was defined a *Agreement index* as the average of the scores of the different responders. Therefore, for N responders to a specific question, the Agreement Index *A* was defined as follows:

$$A = \frac{1}{N}\sum_{i=1}^{N} s_i$$

where s_i is the score associated to the answer of the *i*-th responder. The spread of the responders' answers was measured through the standard deviation of their scores i.e.:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(s_i - A)^2}{N-1}}$$

3. REVIEW OF THE 'SCREENING METHOD'

The first topic submitted to review was the screening method used to identify the critical installations to be submitted to the hazard identification analysis, and the effectiveness of its implementation in the case of the reference establishment.

As previously mentioned, the screening method used by the reference establishment' operator was the one proposed in the "Purple Book" CRP 18E guideline.

In general the response of the reviewers was very positive both in terms of:

- *Acceptability of the method used* (**Q1**), and
- *Effectiveness of its implementation* (**Q2**).

This response is outlined in figure 2 were the correspondent Agreement Index is depicted. Some criticism was raised by a responder on that fact that the methodology does not take into account of possible domino effects. Some doubts were also expressed with regard to the completeness of the list of critical installations and specifically the absence of the natural gas pipeline, which is missing in the report. A responder showed also some perplexities on the exclusion of chlorine from the list of critical installations, but such a concern was not explained in details.

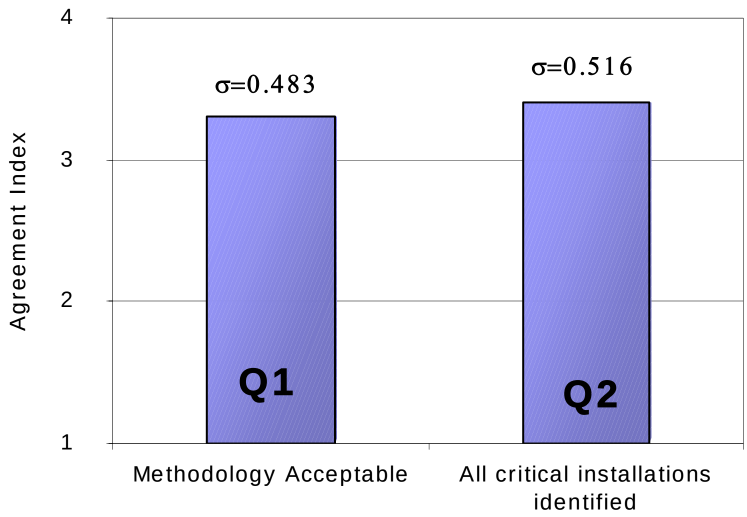


Figure 2: Review of the screening method.

With regard to the acceptability of the proposed methodology from a Competent Authority point of view, 100% of the responders gave positive answers. Some declared that no specific methodology is imposed in their Country, but the operator is free to use whatever methodology provided that its effectiveness can be demonstrated.

4. REVIEW OF THE HAZARD IDENTIFICATION ANALYSIS

4.1 General

The Hazard Identification Analysis has been indicated by the operator of the reference plant has an HAZOP. However this HAZOP is quite atypical and several reviewers have rightly suggested indicating it as Failure Mode and Effects Analysis (FMEA) or more generically Process Hazard Analysis (PHA). As a matter of fact, this Hazard Identification Study is not based on the analysis of how the process parameters could vary from normal operation, but on the failure of single components. However it was considered as totally acceptable due to the simplicity of the processes of the involved installations.

The perception of the reviewers about the format of the Hazard Identification Analysis and the clearness of the assumptions made is depicted in figure 3. Even though most of the responders were positive on these issues, there was a disagreement of about 20%. One of the main criticisms was that the explanation of the location of initiating events was not always completely clear. A reviewer also stated that the scope of the Hazard Identification has to be clearly described in the analysis, and that this aspect was missing in this case.

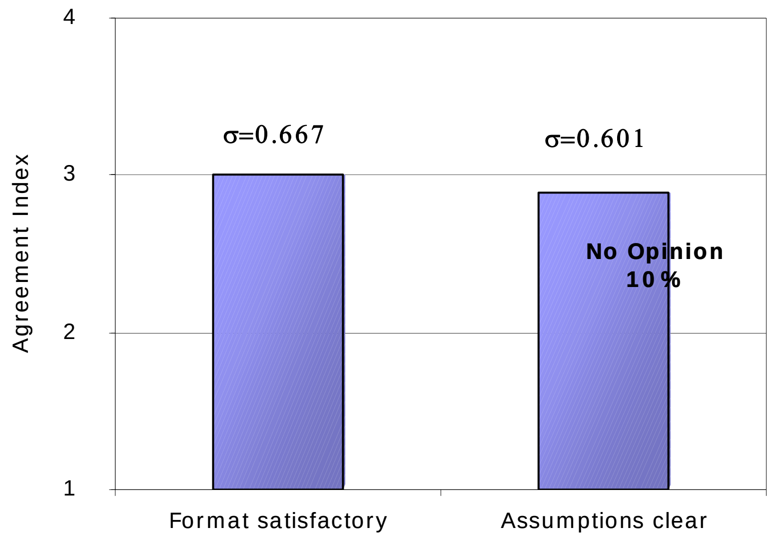


Figure 3: Review of the Hazard Identification Analysis (Format and Assumptions)

With regard to the opinion of the reviewers on the completeness of the list of Scenarios, the quality of Scenarios' description and risk ranking, the situation is shown in figure 4.

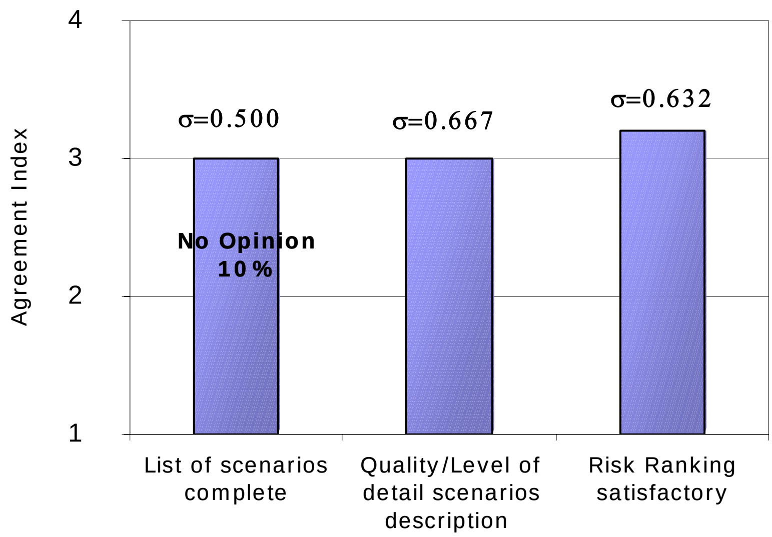


Figure 4: Review of the Hazard Identification Analysis (completeness, description, risk ranking)

The majority of the responders gave positive answers. Some of them also emphasised that fact that completeness of hazards' list is a fundamental issue, as it would clearly influence the whole following risk analysis study. However, it was noticed that the present study does not refer to other possible hazards, not specifically mentioned, which could have been screened out due to their low likelihood/consequence. In these situations and in order to check for completeness, the reviewer is often obliged to conduct his/her own hazard identification analysis. This is obviously not acceptable from a Competent Authorities' perspective.

It was mentioned the lack of a potential Scenario involving overfilling of ethanol tanks. As this event is not totally unlikely, some explanations should have been given.

It was emphasised that a clear distinction between rupture and leakage of a pipe should have been made. These two situations could lead to completely different Scenarios in terms of the consequences associated therewith.

For risk ranking, it was suggested to extend the severity and likelihood scales, for instance from 1 to 10. This would avoid the quite illogical situation in which the catastrophic tank rupture (Scenario 1.1: S = 4, L = 1) and the flange leakage with unlockable wagon valve (Scenario
1.5: S = 2, L = 2) would receive the same risk ranking and imply equal importance to risk.

Acceptability of this Hazard Identification Analysis from a the Competent Authorities standpoint
All the ten reviewers belonging to nine of the newly associated and candidate countries, declared that the present Hazard Identification Analysis would be considered as acceptable by the Competent Authorities in their countries. *Therefore it is impossible to find any significant difference among the participating countries in this context*.

Some perplexities were raised by 2 responders only. In one case the negative response was due to the lack of conclusions in the hazard identification study, which are supposed to provide guidance for the definition of further improvement actions and the additional measures to be taken. It was emphasised that prevention and mitigation measures were often mixed up in the study and many cases not described with the proper level of detail. In the second case, the negative response was associated to the lack of proper consideration of domino effects within the HAZOP.

Other General Comments
The installations of the reference establishment are characterised by relatively simple process. Therefore, it is quite obvious that the hazard identification analysis conducted by the operator would address all major hazards. However for more complex installations, it is necessary to provide a more detailed and well-documented study for hazard identification. Only in this way the reviewer of the safety report will be able to follow all steps of the performed analysis and to check the assumptions and the associated limitations.

The hazard identification study should provide full explanation/description of all statements and assumptions within described (e.g. time required to implement a mitigation action). All the systems having relevance for safety have to be clearly described (e.g., tank wagon heating system, valves, etc.). Reference the conformity of the used equipment to the actual standards and the safety regulations has to be present. A clear distinction between human and mechanical failures should be made.

4.2 Review Scenario by Scenario

Node: 1. Sulphur-dioxide tank wagon in the plant

K111: Tank rupture

Causes: 1. Mechanic impact (hydrochloric acid or alkali tank wagon, once in every 2 -3 weeks).
Scenario K111 54 t SO_2 release to the environment as a consequence of the catastrophic rupture of the SO_2 tank wagon due to mechanical impact with hydrochloric acid or alkali tank wagon. Tank temperature: 40 C°; pressure: tension related to 40 C°; height: 1.1 m; outflow to concrete surface, no bund.
Risk Ranking: *S = 4: "Out-site large number of death".* *L = 1: "Not accepted to occur during facility life".* *RR = 4:" Small and middle out-site risk".*

Safeguards: None
Recommendations: None

The reviewers were asked about their perception on the completeness of causes for this event. As a response, **40%** of the reviewers agreed that the description was satisfactory whilst **60%** declared that some other potential causes for catastrophic rupture had not been considered.

Amongst the causes not taken into account by the operator they addressed the following:

- Design errors.
- Corrosion or other material defect/degradation mechanisms.
- Overpressure in the tank due to overheating.
- External events (e.g. fire in the proximity of the tank wagon).

It was also emphasised that there is a lack of description of how the mechanic impact could occur, whether any protection measure is in place or not.

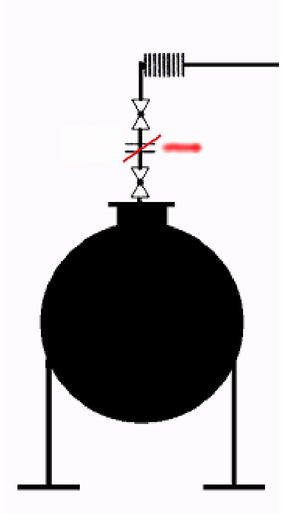
With regard to K111 Scenario, the majority of reviewers (**70%**) declared that despite the very low likelihood, this Scenario should be considered as *credible* and needs to be taken into account in the risk analysis. In addition, regardless of its credibility 80% of the reviewers stated that this Scenario would be required by the Competent Authorities in their country anyhow, and it would be considered as the worst-case Scenario.

All reviewers agreed with the ranking given by the operator (with one exception in which the responder proposed a higher likelihood without clear explanation i.e. L = 3).

As the operator did not mention any safeguards and recommendations, the reviewers were also asked to suggest any other safeguards or protection measures they would consider as appropriate. **60%** of the reviewers provided with some recommendations, which are summarised below:

- In order to prevent the spread of liquid in case of tank rupture, a specific bund/fence should be put in place.
- Water sprays should be set in order to abate SO_2 vapours in case of tank rupture.
- The use of certified wagons is recommended.
- Rail barriers should be mentioned explicitly in the hazard identification analysis.
- The existence of specific operation instructions, training and maintenance should be mentioned explicitly in the hazard identification analysis.
- Specific means of protection for the operators should be clearly specified.
- Internal transport code of conduct has to be set.
- In case of accident, a specific attention should be paid to ethanol storage tank n.3 that is located nearby. As a matter of fact, SO_2 has explosive properties when in contact with ethanol.

K121: Isolable SO_2 leakage on the pipe, before the pipe failure protector valve

Causes 1. Flange leakage.	
Scenario K121 Isolable leakage of equivalent ø10 mm due to failure of the flange; horizontal outflow during 20 minutes (when SO_2 sensors are available) or during 30 minutes* (when SO_2 sensors are not available); height: 5 m; pressure: tension related to 40 Cº. * 10 minutes for diagnosis and then 20 minutes for action.	
Risk Ranking *S = 1: "In-site health injury or health impacts".* *L = 3: "Could occur several times during facility life".* *RR = 3: "Small and middle out-site risk".*	
Safeguards 8 SO_2 sensors, 5 ppm sensitivity Operation permanently attended by the operator, who is able to detect the leakage after 10 minutes from the release.	
Recommendations None.	

For K121 Scenario and with reference to the clearness of the Scenario description and the acceptability of the hypothesis made, the Agreement *Index* was quite high: **3.4** (σ = 0.516) and **3.5** (σ = 0.527), respectively. In both cases all the reviewers replied either "*totally agree*" or "*tend to agree*".

Amongst the most relevant comments:

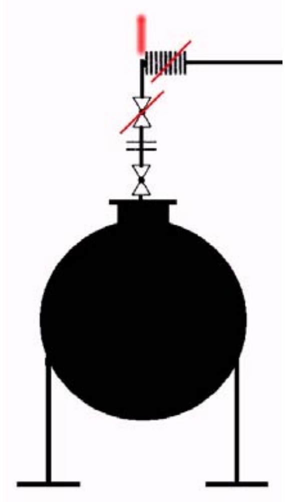
- Causes have to be more specific (e.g., "*flange leakage due to …*")
- The estimated amount of released SO_2 should appear in the hazard identification study
- The release time should be better explained and justified. As a matter of fact the time considered for operator's response seems to be quite optimistic and should be justified.
- A clear distinction should be made between leakage and rupture. This would lead to quite different consequences.

With regard to risk ranking, the totality of the reviewers agreed with the choice made by the operator. Someone observed only that in case of rupture the ranking should be revised, and additional safety measures should be taken.

For safeguards, the majority of responders declared that they are described correctly (Agreement index = **3.111**, s = 0.601, 10%: *no opinion*), however some reviewers underlined that the issues described (sensors, presence of operators) are more mitigation measures than safeguards. For this reason they stated that the operator should be encouraged to identify also measures to prevent Scenario from happening. It was also suggested to describe how to stop tank heating is case of release.

As the operator did not mention any recommendation, the reviewers were also asked to provide with some suggestions. Some of them suggested the use of an additional safety system, consisting of an automatic shut-off valve, activated by the SO_2 sensors. A proper monitoring and inspection plan should further reduce the likelihood of occurrence of this event.

K131 Isolable SO_2 leakage on the flexible pipe

Causes 1. Flexible pipe-end rupture AND failure of the pipe rupture protection-valve.	
Scenario K131 Isolable leakage due to flexible pipe rupture AND failure of the protection valve (spring valve); vertical outflow from ø25 mm during 20 minutes (when SO_2 sensors are available) or during 30 minutes* (when SO2 sensors are not available); height: 5 m; pressure: tension related to 40 Cº. * 10 minutes for diagnosis and then 20 minutes for action.	
Risk Ranking *S = 1: "In-site health injury or health impacts".* *L = 3: "Could occur several times during facility life".* *RR = 3:" Small and middle out-site risk"*	
Safeguards 8 SO_2 sensors, 5 ppm sensitivity. Operation permanently attended by the operator, who is able to detect the leakage after 10 minutes from the release.	
Recommendations None	

For K131 Scenario and with reference to the clearness of the Scenario description and the acceptability of the hypothesis made, the Agreement *Index* was quite high: **3.4** (σ = 0.516) and **3.2** (σ = 0.412), respectively. In both cases all the reviewers replied either "*totally agree*" or "*tend to agree*".

The main comments were similar to the previous case:

- The amount of released SO_2 should appear in the hazard identification study.
- The release time should be better explained and justified. As a matter of fact the time considered for operator's response seems to be quite optimistic and should be justified.

For to risk ranking, the totality of the reviewers agreed with the choice made by the operator.

With regard to safeguards, the majority of responders declared that they are described correctly (Agreement index = **3.111**, s = 0.702), however also in this case, some reviewers underlined that the issues described (sensors, presence of operators) are more mitigation measures than safeguards. For this reason they stated that the operator should be encouraged to identify also measures to prevent Scenario from happening.

As a recommendation, some of the reviewers suggested the use of automatic systems to stop the flux of SO_2 driven by the sensors, and the setting of a proper monitoring and inspection plan.

<u>Isolable SO2 leakage before the starch industry on the pipe bridge</u>

Causes 1. Pipe rupture on the pipe bridge AND failure of the pipe failure protection valve (spring valve) AND failure of the drain valve (valve after flexible pipe and before pipe bridge).
Scenario None.
Risk Ranking *S = 1: “In-site health injury or health impacts”.* *L = 2: “Could occur once during facility life”.* *RR = 2: “In-site risk”.*
Safeguards Operation permanently attended by the operator, who is able to detect the leakage after 10 minutes from the release.
Recommendations None.

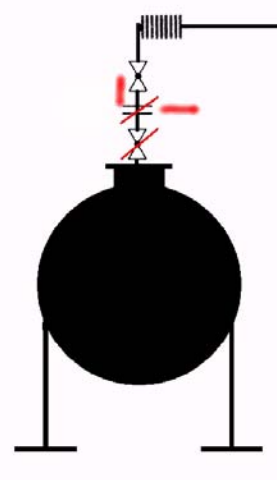
For this event that does not lead to a Scenario, the reviewers were asked whether they agreed on this statement. The Agreement *Index* was **2.889** (σ =0.782), with **10**% of responders who declared of not having a specific opinion. Somebody also suggested that causes should be more specific, by explaining why and under which conditions the components may fail.

For risk ranking, all the reviewers agreed with the choice made by the operator.

For safeguards, the Agreement Index was **3.333** (σ = 0.866), with 10% of the responders who declared of not having a specific opinion.

Also for this case it was suggested to make a clear distinction between leakage and rupture of the pipe, because this could lead to different Scenarios.

<u>K151 Not isolable SO_2 leakage on the pipe, before the pipe failure protector valve</u>

Causes 1. Flange leakage AND failure of the tank wagon valve.	
Scenario K151 Not Isolable leakage of equivalent ø10 mm due to failure of the flange AND the tank wagon valve; horizontal outflow during 20 minutes (when SO_2 sensors are available) or during 30 minutes* (when SO2 sensors are not available); afterwards, vertical outflow from ø40 mm for 10 minutes (time required for mounting the shut-off valve); height: 5 m; pressure: tension related to 40 Cº. * 10 minutes for diagnosis and then 20 minutes for action.	
Risk Ranking S = 2: “*In-site personal accidents or severe injury”.* *L = 2: “Could occur once during facility life”.* *RR = 4: “* *Small and middle out-site risk”.*	
Safeguards 8 SO_2 sensors, 5 ppm sensitivity Operation permanently attended by the operator, who is able to detect the leakage after 10 minutes from the release.	
Recommendations 1. Stopping the leakage is recommended, by mounting a flanged shutoff valve.	

For K151 Scenario and with reference to the clearness of the Scenario description and the acceptability of the hypothesis made, the Agreement *Index* was **3.2** in both cases (with σ = 0.789and σ = 0.422, respectively). With regard to clearness, the higher spread of data (σ =

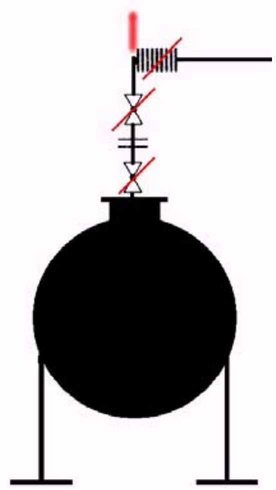
0.789) was also due to the higher number of responders (20%) who declared: "*tend to disagree*". The main criticism was due to the lack of information on the quantity of the released substance, the outflow mechanism, and the justification about the time required executing the mitigation measure.

For risk ranking, all the reviewers agreed with the choice made by the operator.

With regard to safeguards, the Agreement index was **3.2** (σ = 0.422), and also in this case, similar comments have been given (the proposed safeguards are mitigation actions, only).

For recommendations, almost the totality of the responders did agree with the operator. However it was questioned that mounting of a shut-off valve of a wagon in such a short time given any weather, visibility and accessibility conditions (due to leakage around) could be justified only if the operators has proved experience and training.

K116 Not Isolable SO_2 leakage on the flexible pipe

<table>
<tr><td>Causes
1. Flange leakage AND failure of the pipe rupture protection valve AND failure of the tank wagon valve.</td><td rowspan="5"></td></tr>
<tr><td>Scenario K161
Not Isolable leakage due to flexible pipe rupture AND failure of the protection valve (spring valve) AND failure of tank wagon valve; vertical outflow from ø25 mm (when SO_2 sensors are available) or during 30 minutes* (when SO_2 sensors are not available); afterwards vertical outflow from ø40 mm during 10 minutes (time required for mounting the shut-off valve);
height: 5 m; pressure: tension related to 40 Cº.

* 10 minutes for diagnosis and then 20 minutes for action.</td></tr>
<tr><td>Risk Ranking
S = 2: "In-site personal accidents or severe injury".
L = 2: "Could occur once during facility life".
RR = 4: "Small and middle out-site risk".</td></tr>
<tr><td>Safeguards
8 SO_2 sensors, 5 ppm sensitivity.
Operation permanently attended by the operator, who is able to detect the leakage after 10 minutes from the release.</td></tr>
<tr><td>Recommendations
1. Stopping the leakage is recommended, by mounting a flanged shutoff valve.</td></tr>
</table>

For K161 Scenario and with reference to the clearness of the Scenario description and the acceptability of the hypothesis made, the Agreement *Index* was **3.222** (**σ**=0.441) and **3.111** (σ = 0.333), respectively), where all the reviewers declared "*totally agree*" and "*tend to agree*" (with 10% of "*no opinion*" in both cases).

For risk ranking, all the reviewers agreed with the choice made by the operator.

With regard to safeguards, the Agreement index was **3.222** (σ = 0.667), and also in this case, similar comments have been given (the proposed safeguards are mitigation actions, only)

For recommendations, **70%** of responders declared to agree with the operator whilst **30%** stated of not having a specific opinion.

Not Isolable SO_2 leakage before the starch industry on the pipe bridge

Causes 1. Flexible pipe-end rupture AND failure of the pip failure protection valve AND failure of the tank wagon valve AND failure of the drain valve.

Scenario None.
Risk Ranking *S = 2: "In-site personal accidents or severe injury".* *L = 1: "Not accepted to occur during facility life".* *RR = 2: "In-site risk".*
Safeguards 8 SO_2 sensors, 5 ppm sensitivity. Operation permanently attended by the operator, who is able to detect the leakage after 10 minutes from the release.
Recommendations 1. Stopping the leakage is recommended, by mounting a flanged shutoff valve.

For this event that does not lead to a Scenario, the reviewers were asked whether they agreed on this statement. The Agreement *Index* was **3.000** (σ =1.000), with a large number of responders who declared of not having a specific opinion (**30%**). Somebody also suggested that causes should be more specific, by explaining why and under which conditions the components may fail.

For risk ranking **70%** of the reviewers agreed with the choice made by the operator, **10**% declared of not having a specific opinion, whilst the **20**% scored slightly higher values of likelihood and severity.

For safeguards the Agreement Index was **3.250** (σ = 0.707), with **20**% of the responders who declared of not having a specific opinion.

Finally **80**% of the reviewers declared that the recommendation proposed by the operator is acceptable.

<u>Overpressure in the tank wagon</u>

Causes 1. Weather conditions and tank overheat
Scenario None.
Risk Ranking *S = 1: "In-site health injury or health impacts".* *L = 2: "Could occur once during facility life".* *RR = 2: "In-site risk".*
Safeguards 1.1. Pressure- release valve.
Recommendations None.

For this event that does not lead to a Scenario, the reviewers were asked whether they agreed on this statement. The Agreement *Index* was the lowest if compared to all previous questions, being **2.571** (σ =1.134). **20%** of the responders declared of not having a specific opinion on this matter, and **20%** declared to "*totally disagree*" with the sentence. The main reason for this was the fact that the tank wagon stands for ca. a month in the due unloading location that is a relatively long time, and the heating system used to "pump" the SO_2 in the pipeline is not clearly described. Besides, no information is given about the availability of a cooling system.

For risk ranking, all the reviewers agreed with the choice made by the operator that is quite in contradiction with the previous response.

Risk ranking **70%** of the reviewers, agreed with the operator, 10% declared of not having a specific opinion on this matter, whilst **20%** expressed they disagreement but with different opinions on the likelihood of occurrence of this accidental event (higher and lower than the given value, respectively).

For safeguards, the Agreement index was **3.000** (σ = 0.816), and also in this case, similar comments have been given (the proposed safeguards are mitigation actions, only). Finally, **60%** of responders proposed additional recommendations, which included: the possible use of wall protection, and the installation of temperature/pressure sensors for monitoring operation in the case of overheating. Cooling down measures and should be put in place.

Node 2: Sulphur-dioxide wagon change

K211: Tank rupture

Causes 1. Mechanic impact
Scenario K211 54 t SO_2 release to the environment as a consequence of the catastrophic rupture of the SO_2 tank wagon due to mechanical impact during wagon change. Tank temperature: 40 Cº; pressure: tension related to 40 Cº; height: 1.1 m; outflow to concrete surface, no bund.
Risk Ranking *S = 4: "Out-site large number of death".* *L = 1: "Not accepted to occur during facility life".* *RR = 4:" Small and middle out-site risk".*
Safeguards 1.1. Rail barriers and clearance protection.
Recommendations 1. It is recommended not to rack hydrochloric acid or alkali during wagon changing.

With regard to the K211 Scenario, there was a better balance between the reviewers who declared that this Scenario is credible and those who declared that it is too conservative (**50%**). However, regardless of its credibility **90**% of the reviewers stated that this Scenario would be required anyhow by the Competent Authorities in their country, and it would be considered as the worst-case Scenario. It was also emphasised that despite the different cause, this Scenario has to be analysed together with K111 by listing all possible causes of impact. Again it was suggested to include material degradation mechanisms and possible fires in the proximity of the tank wagon as other possible causes of catastrophic rupture.

All reviewers agreed with the ranking given by the operator.

For safeguards, the Agreement Index regarding their acceptability was **3.200** (σ = 0.632), and some of the reviewers suggested to consider the possibility to include: (*i*) special bund to limit the spread of the liquid in case of rupture, (*ii*) the installation of water sprays for vapours' abating and (*iii*) indication for individual protection measures. **70%** of the reviewers considered acceptable the recommendation proposed by the operator, and also for this case it was suggested to take specific measures to limit the consequences to ethanol storage 3 in case of accident. It was also recommended to explicitly mention that no activity should be allowed during tank wagon change.

K221: Not isolable SO_2 release before the shut-off valve line

Causes 1. 1 Flange or connecting fails AND failure of the tank wagon valve.
Scenario K221 Not Isolable leakage of due to failure of flange connection AND failure of tank wagon valve; vertical outflow from ø40 mm during 10 minutes (time required for mounting the shut-off valve);. Height: 5 m; pressure: pressure: tension related to 40 Cº.

Risk Ranking *S = 2: "In-site personal accidents or severe injury".* *L = 2: "Could occur once during facility life".* *RR = 4:" Small and middle out-site risk".*
Safeguards 1.1. Two people are attending the process operation. They mount a flanged shut-off valve in 10 minutes in case of leakage.
Recommendations 1. The soonest intervention to stop the flow, by the locker armature, what is kept at the crew.

For Scenario K221 and with reference to the clearness of the Scenario description and the acceptability of the hypothesis made, the Agreement *Index* was: **3.333** (σ = 0.707, *no opinion*: 10%) and **3.444** (σ = 0.726), respectively.

For risk ranking, **80**% of the reviewers agreed with the choice made by the operator, whilst the rest suggested a higher value for likelihood of occurrence (L = 3).

For safeguards, an Agreement Index of **3.333** (σ = 0.866, *no opinion 10%*) was the global response of reviewers, but 20% of the responders who *tended to disagree* regarding the clearness o their description, expressed some doubts on the response time of the operators and declared a better explanation of this issue should be given. Besides, also in this case there is no reference to preventive measures. Finally, **70**% of the reviewers agreed on the proposed recommendations, whilst 10% declared not having an opinion.

Node 1&2: Ethanol Tanks (1-2-3-10 & 6-7)

A1x_y[8] Catastrophic rupture

Causes 1. Material defect. 2. Pipe branch rupture on a not isolatable section.
Scenarios: **1st type** : A11_1 – A11_2 – A11_3 – A11_10 – A11_6 – A11_7 **2nd type**: A12_1 – A12_2 – A12_3 – A12_10 – A12_6 – A12_7 **1st type.** 5000, 2000, 930, 230, 700, 700 m^3 ethanol release to the environment due to catastrophic rupture of the tank. Temperature: environmental; pressure: atmospheric. Bunds are respectively: 1500, 817, 900, 100, 113, 113 m^2, which correspond to the following volume containments: 4000, 1939, 930, 231, 700, 700 m^3. **2nd type.** 5000, 2000, 930, 230, 700, 700 m^3 ethanol release to the environment due to not isolable pipe rupture (ø80 mm); Temperature: environmental; pressure: atmospheric. Discharge velocity depends on the hydrostatic head. Liquid levels are respectively: 13.2, 10, 4.6, 9.3, 8.9, 8.9 m. Bunds are respectively: 1500, 817, 900, 100, 113, 113 m^2, which correspond to the following volume containments: 4000, 1939, 930, 231, 700, 700 m^3.
Risk Ranking *S = 4: "Out-site large number of death".* *L = 1: "Not accepted to occur during facility life".* *RR = 4:" Small and middle out-site risk".*
Safeguards Bunds are designed to contain all tank content Bunds are designed to contain all tank content
Recommendations Installation of alcohol detectors, which are set to very high sensitivity.

[8] x = 1,2 (1 = Node 1; 2 = Node 2); y: tank number

The list of above Scenarios refers to the ethanol tanks. As the only difference amongst them is the volume and the location, they have been all treated together.

80% of the reviewers agreed that the operator has identified all significant causes. Those, who disagreed, declared that other elements have to be considered, as for instance: thermal stress and mechanical impacts. It was also emphasised that more detail should be given to the type and extent of possible defects or degradation mechanisms.
Regarding the credibility of the Scenario, a relatively balanced situation was observed. Indeed, **60**% of the reviewers stated that these Scenarios are credible whilst **40**% declared that they are too conservative. However, regardless of their credibility **80**% of the reviewers stated that these Scenarios would be required by the Competent Authorities in their country anyhow, and they would be considered as worst-case (10% expressed no opinion).

All reviewers agreed with the ranking given by the operator.

For safeguards, the Agreement Index regarding their acceptability was **3.111** (σ = 0.782, 10% "*no opinion*"), and some of the reviewers suggested to include information on how to remove the ethanol from the second containment in case of release. Again it was mentioned that there are no protection measures. **80**% of the reviewers declared that the recommendation is acceptable, and it was mentioned that the installation of detectors requires a detailed analysis of the dispersion characteristics.

Overpressure in the tanks

Causes 1. Vacuum/pressure safety valve
Scenario None.
Risk Ranking *S = 2: "In-site health injury or health impacts".* *L = 1: "Not accepted to occur during facility life."* *RR = 2: "In-site risk".*
Safeguards Resistance of the tank wall and presence of the outside bund.
Recommendations None.

For this event that does not lead to a Scenario, the reviewers were asked whether they agreed on this statement. The Agreement *Index* was quite low if compared to the previous cases **2.286** (σ=1.113), with a large number of responders who declared of not having a specific opinion (30%) and a relatively high number of responders who disagreed (40%). Due to the possible severity of the consequences it was also suggested to conduct a detailed analysis on the occurrence frequency of such an event. In addition it was highlighted that (*i*) vacuum/pressure safety valves may be blocked and (*ii*) overheating can occur, and (*iii*) overfilling due to failure of the level sensors may be an issue. Finally, from the description it is not perfectly clear whether this event includes also the vacuum case, which could also lead to a release due to tank failure.

For risk ranking **80%** of the reviewers agreed with the choice made by the operator, **10**% declared of not having a specific opinion, whilst the **10**% scored a lower severity (S = 1).

For safeguards the Agreement Index was **3.286** (σ = 0.756), with a quite high number of responders who declared of not having a specific opinion (30%).

Finally **40**% of the reviewers provided with other elements to be considered as possible recommendations:

- Definition of proper inspection plans for the tanks and pipeworks.
- Inclusion of additional safety pressure valve.
- Remote-control switch for cooling the system.

Pressure decrease during unloading

Causes 1. Loss of power supply.
Scenario None.
Risk Ranking *S = 1: "In-site health injury or health impacts".* *L = 1: "Not accepted to occur during facility life".* *RR = 1: "In-site risk".*
Safeguards None.
Recommendations None.

For this event that does not lead to a Scenario, the reviewers were asked whether they agreed on this statement. The Agreement *Index* was **3.000** (σ =1.069), with 20% of responders who declared of not having a specific opinion and a 20% of responders who disagreed. The main criticism was that loss of power cannot influence pressure decrease during unloading.

For risk ranking **70%** of the reviewers agreed with the choice made by the operator, **10**% declared of not having a specific opinion, whilst the **20**% scored a higher value of the likelihood. This because loss of power supply should be considered as relatively frequent event, and unless emergency power source is available, likelihood of power failure should not be rated lower than L = 3.

For this event, the reviewers did not suggest any significant safeguard or recommendation.

Rupture of the pipe next to the tanks

Causes 1. External mechanic impact (tree, truck, etc).
Scenario None.
Risk Ranking *S = 1: "In-site health injury or health impacts".* *L = 1: "Not accepted to occur during facility life".* *RR = 1: "In-site risk".*
Safeguards None.
Recommendations None.

For this event that does not lead to a Scenario, the reviewers were asked whether they agreed on this statement. The Agreement *Index* was the lowest of this review **2.750** (σ =1.035), with 20% of responders who declared of not having a specific opinion and a 40% of responders who disagreed (40%). The main criticism was that pipeworks are very sensitive to release.

For risk ranking all reviewers agreed with the choice made by the operator.

For this event, the reviewers did not suggest any significant safeguard or recommendation.

5. SUMMARY OF THE HAZARD IDENTIFICATION ANALYSIS REVIEW

This section summarises the outcome of the review of the BEQUAR members of the Hazard Identification Analysis conducted by the Reference Establishment's operator. More specifically, it represents a digest, of the BEQUAR reviewers' position with regard to the appropriateness of the identified Scenarios, their description and the proposed safeguards. A point to note is that the representation of the group position as a whole required some simplifications. The results presented represent, therefore, general trends and have not statistical significance.

In general, the proposed Hazard Identification Analysis was considered acceptable by the BEQUAR reviewers. The only two exceptions were augmented by the lack of proper conclusions to guide for possible improvement and mitigation actions and for the lack of consideration of domino effects.

Particularly interesting is the comparison of the reviewers' position on the most catastrophic Scenarios (figure 5 and 6). More specifically, figure 5 gives the percentage of reviewers considering the mentioned Scenarios are credible (blue bar) or too conservative (purple bar). The most credible Scenario resulted: the catastrophic rupture of the SO_2 tank wagon as a consequence of the impact with the alkali/chlorine tank wagon (K111), whilst the catastrophic rupture of ethanol tanks (A11) was considered the less credible. Perfect balance (50%) was found for the catastrophic rupture of the SO_2 tank wagon during wagon change (K211).

Figure 5 summarises the results on the question whether the Competent Authorities of the reviewers' countries would require a detailed analysis of these Scenarios anyhow and regardless of their credibility. In all these cases, a common positive response was noticed, by demonstrating that high consequence/low probability Scenarios are always taken in great consideration by the Competent Authorities.

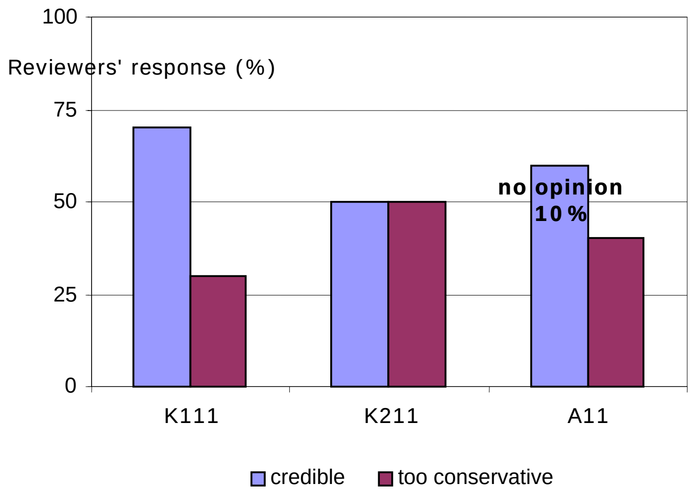


Figure 5: Credibility of catastrophic Scenarios

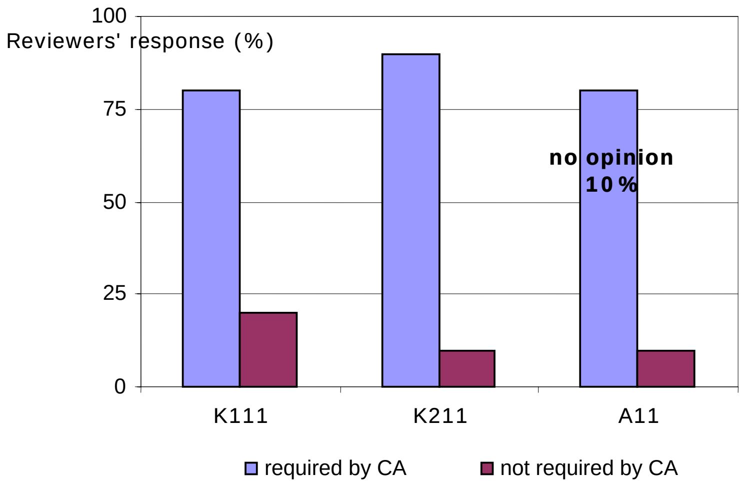


Figure 6: Requirement by the CAs of the catastrophic Scenarios

For the other Scenarios, the Agreement Indexes and the standard deviations, which give a measure of the responses' scatter, are depicted in Figures 7 and 8. The values reported refer to the perception of the reviewers with regard to the description of the Scenario itself (blue bar), the acceptability of hypotheses made (purple bar) and the description of safeguards (yellow bar).

For all Scenarios the Agreement Indexes were quite high by exceeding the value of 3. A greater consensus was found on the Scenario formulation then the description of safeguards.

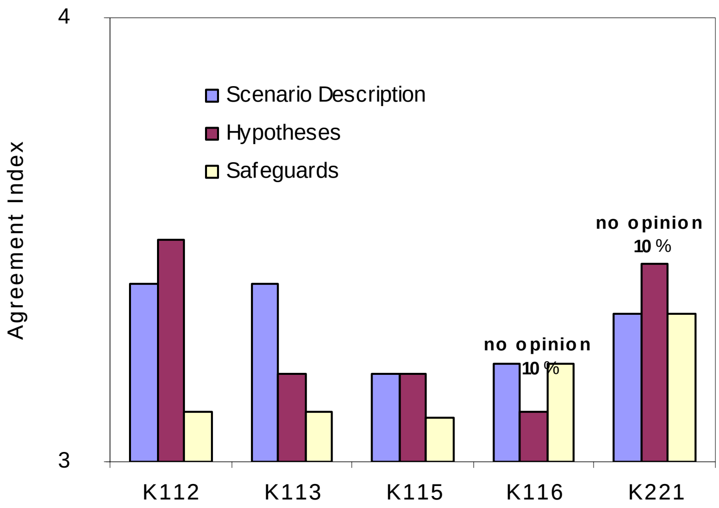


Figure 7: Agreement indexes vs. Scenario

Figure 8: Spread of reviewers' response vs. Scenario

For the events that did not lead to accidental Scenarios, the agreement index is reported in figure 9. In this case the level of agreement was definitely lower if compared to the previous case, with a higher indecision level (from 10 to 30% of "no opinion"). The spread of responses is depicted in Figure 10. Particularly interesting is the case of tank overpressure both for SO_2 (K118) and A12 (Ethanol). These scored considerably less, which means that not all BEQUAR responders agreed on the fact that these events should be excluded from the detailed analysis.

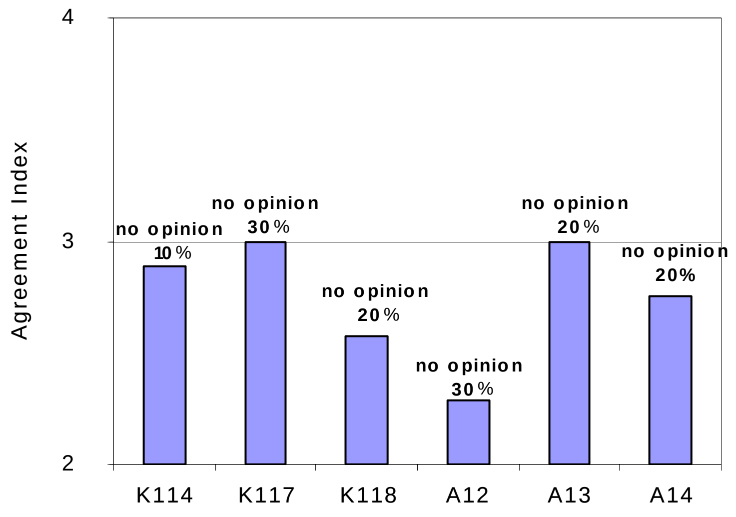


Figure 9: Events that do not lead to a Scenario

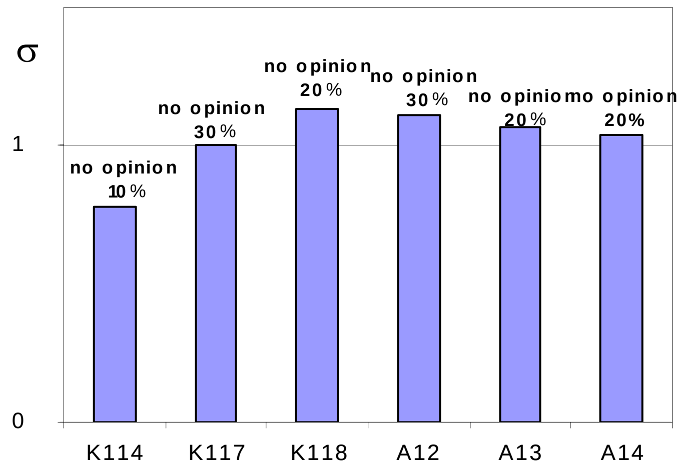


Figure 10: Spread of reviewers' response vs. Scenario

REVIEW OF THE FREQUENCY DATA

1. INTRODUCTION

The present chapters summarises the main conclusions of the review on the reference establishment frequency data, which was conducted by nine members of BEQUAR. As usual, the data referred to the accident Scenarios postulated through the Hazard Identification Analysis.

The accident frequency data related to the reference plant, which were submitted to review, were provided by the JRC who played the role of the operator for this exercise. These were elaborated by modifying some of the original data, assumptions and calculations as provided by the actual operator of the reference plant. The difference from the original data set makes this frequency data review totally uncorrelated from the actual case. For this reason, it is possible to assert unambiguously the non addressability of the conclusions of this study to the actual plant used as the reference plant.

The data provided by the reviewers were compared to the reference values through graphics as shown in the following sections. In order to maintain anonymity, it was decided to indicate each responder through an integer number without quoting their name and affiliation.

Several sources were quoted by the reviewers which were used for their analysis[9,10,11,12,13,14,15,16,17,].

In several cases it was stressed that human factors related events are always very difficult to be assessed because they depend on several factors as for instance: (*i*) the specific instructions and procedures which are available and used in the plant and (*ii*) the specific safety culture within the organisation involved.

A point to note is that frequency assessment is a quite delicate task in any Quantitative Risk Assessment process. This because of the uncertainty associated to the data and the related effect on the final outcome of the overall risk analysis. For this reason, a fundamental step in the benchmark is to get a feedback from the BEQUAR reviewers about their perception on the frequency values given and the general difficulties associated to this process.

2. SUMMARY OF FREQUENCY DATA

The present section summarises the results of the accident frequency analysis of the reference establishment. As stated in the introduction, <u>the original data provided by the operator were taken as a basis for this analysis. However, some of the original data, assumptions and calculation methods have been slightly modified by the JRC in order to differentiate the benchmark from the actual case</u>. In this way it was possible to produce a consistent data set that differs from the original case and, therefore, that can be object of review without restrain.

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[9] "Red Book" - CPR12E “Methods for Determining and Processing Probabilities”
[10] Guidelines for Process Equipment Reliability Data, 1989 Center for Chemical Process Safety/AIChE
[11] Jefferson Lab Environment, Health & Safety (EH&S) Manual , Appendix 6500-T1 ODH
[12] WASH 1400 (The Rasmussen Report), Nuclear Regulatory Commission 1975
[13] Smith, DJ, “Reliability and Maintainability in Perspective”, 2nd. and 3rd. editions, Macmillan,. London, 1985
[14] Swierk “Development of the generic reliability database for chemical installations elements”, 1999 (in Polish)
[15] Batstone, R.J., Tomi, D.T., “Hazard Analysis in Planning Industrial Developments”, Loss Prevention, 13, 7, 1980
[16] Internal databases based on expert judgment &databases commonly used for nuclear installations
[17] http://www.roymech.co.uk/index3.htm

By following this approach any misinterpretation of the data and any possible disagreement on the methods used to calculate the frequencies of the top events, will not be addressable to the real situation with regards to the reference plant.

1. The system "*sulphur-dioxide*" has been modelled considering two main phases:

- All actions necessary to start the mission (i.e. arrival of tank wagon + its connection to the plant); no mission time can be considered as all events are human actions (involved Scenarios: K111, K211, K221). In these cases the probability of release (Q) is based on human error probabilities. Then Q is multiplied by the frequency of tank arrivals f_A (n. tanks/year). Therefore the annual frequency of release of toxic gas f_{R1} is given by: $f_{R1} = f_A$ Q release/year = (n. tanks/year) (release/tank).

- The tank wagon is on line. At t = 0 all components are working (a check of them is carried out before starting the discharging operations; if a component is found to be failed the mission is delayed until the repair is completed) and the discharging process lasts 876 hours (mission time). There are 10 missions/year (involved Scenarios: K121, K131, K151, K161). In all of these Scenarios we determine the Expected Number of Failures (W) for a mission of 876 h, i.e. the time needed to discharge of the content of the tank wagon into the plant (release/mission). Then we multiply this value by the number of missions in a year f (mission/year). The annual frequency of release of toxic gas f_{R2} is, therefore, given by: $f_{R2} =$ f W Release/year = (n. missions/year) (release/mission).

2. Different considerations were made for the *"Ethanol"* system, for which no Scenario analysis has been performed.

The hypothesis adopted during the study (for all Scenarios) is that the operator always intervenes in case of accident (there are no events on the type "*the operator does not intervene*").

The following table summarises the data used in the frequency analysis, which was described in an internal report[18]:

[18] Internal report: BEQUAR FRQ Data Rev 2.0, Technical Note, November 2004

Event		q	f (y-1)	failure rate (h-1)	repair time (h)	Mission time (h)
SENSERR	Sensor system doesn't warn the SO2 leakage	9.187E-05				
SENS_SUPPL	Error of the supply of sensor system	6.800E-07		1.700E-07	4.000E+00	8.760E+02
SENS_CU	Error of central unit	9.119E-05		3.800E-06	2.400E+01	8.760E+02
CABLE	Cable error between sensor #X and central unit	5.280E-08		2.200E-09	2.400E+01	8.760E+02
SENSOR	Error of sensor # X	7.195E-04		1.500E-05	4.800E+01	8.760E+02
K111_DEC	Driver decelerates too late	1.000E-03		n.a.	n.a.	n.a.
K111_SL - K211_SL	Exceeding the shunting speed limit (operator fault)	1.000E-05		n.a.	n.a.	n.a.
K121_FL - K151_FL	Flange leakage	3.503E-04		4.000E-07	n.a.	8.760E+02
K131_PV - K161_PV	Failure of the piperupture protector-valve	1.883E-02		2.170E-05	n.a.	8.760E+02
K131_FLEX	Flexible pipe rupture	2.958E-06		3.400E-09	n.a.	8.700E+02
K161_FLEX	Flexible pipe rupture	2.978E-05		3.400E-09	n.a.	8.760E+03
K151_WV - K161_WV K221_WV	Wagon valve is unlockable	4.200E-03		n.a.	n.a.	n.a.
K211_BAR	Operator fault: barrier remains open	3.000E-02		n.a.	n.a.	n.a.
K211_OUT	Fault in sequence of operation: wagon wasn't pulled out of tank	3.000E-05		n.a.	n.a.	n.a.
K221_AF	SO2 release, because of adjustenent error	1.000E-05		n.a.	n.a.	n.a.
K221_GF	SO2 flange leakage because gasket not checked	1.000E-05		n.a.	n.a.	n.a.

Table 5: Frequency data of the initiating events (n.a. = not applicable)

The outcome of the analysis led to the following values of the top events' frequency, which were used for the risk analysis:

Top Event	Q/W	f(y-1)
SENSERR	1.001E-08	
K111	1.000E-08	2.600E-07
K211	9.000E-12	9.000E-11
K221	8.400E-08	8.400E-07
k121_1	3.503E-04	3.503E-03
k121_2	3.219E-08	3.219E-07
k131_1	5.569E-08	5.569E-07
k131_2	5.117E-12	5.117E-11
k151_1	1.471E-06	1.471E-05
k151_2	1.352E-10	1.352E-09
k161_1	2.355E-09	2.355E-08
k161_2	2.164E-13	2.164E-12
A11		5.400E-06
A12		3.000E-07

Table 6: Frequency data of the top events

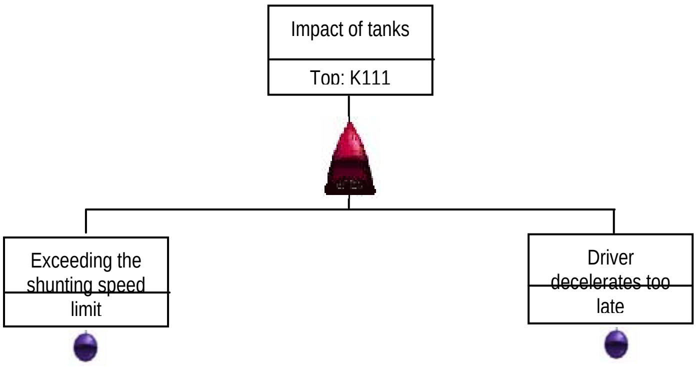
3. REVIEW OF FREQUENCY DATA SCENARIO BY SCENARIO

3.1 SO_2 related Scenarios

Scenario K111

54 t SO_2 release to the environment as a consequence of the catastrophic rupture of the SO_2 tank wagon due to mechanical impact with hydrochloric acid or alkali tank wagon.

The present Scenario is caused by human factors related events, for which the likelihood of occurrence is expressed through a probability (*q)* instead of a frequency. This Scenario is described by the fault-tree shown below:



The reference values for initiating events' probability of occurrence where provided to the BEQUAR members for review. The results of this review are represented in figures 11 and 12, for the events K111_DEC and K111_SL respectively. These figures show the values as perceived by the different partners for the involved initiating events, which are compared to the reference value (bar on the graph).

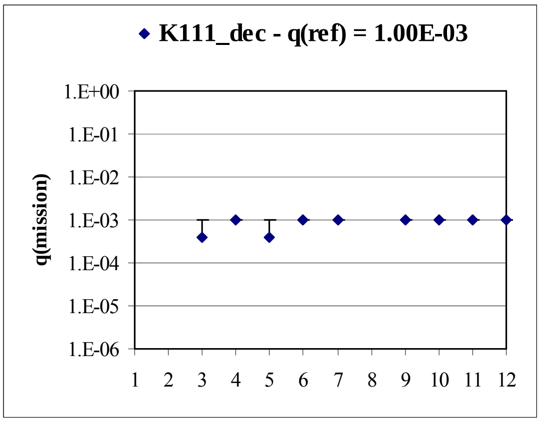


Figure 11: Likelihood of occurrence (per mission) of the K111_DEC event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

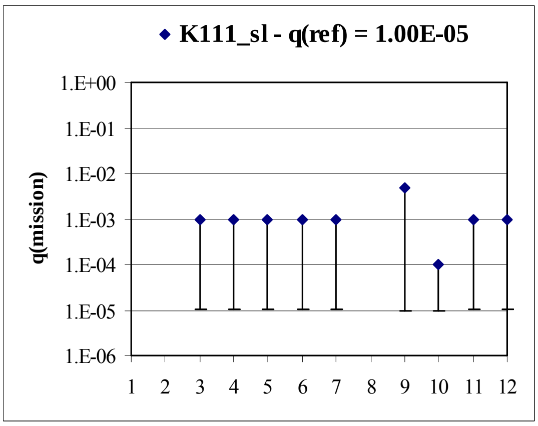


Figure 12: Likelihood of occurrence (per mission) of the K111_SL event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

In order to give a general trend of the BEQUAR group as a whole, it was decided to provide a figure representing a sort of ‘average’ response through the *median* and the *range* of the values proposed. Table 1.1 provides a comparison of these values with the values taken as the reference and submitted for review.

Event	Description	Type	q(ref)	q(median)	q(range)
K111_DEC	*Driver decelerates too late*	Basic	1.0E-03	1.0E-03	4.0E-04 -1.0E-03
K111_SL	*Exceeding the shunting speed limit (operator fault)*	Basic	1.0E-05	1.0E-03	1.0E-04 -5.0E-03

Table 7

As it results from both the figures and the table, the value for the initiating event associated to the *late deceleration of the driver* was considered as appropriate by all the reviewers. On the contrary the likelihood of *exceeding the speed limit* was considered too low. In particular the general response of the reviewers was homogeneous by suggesting a higher value for the likelihood of occurrence (ca. 2 orders of magnitude on the average). This was mainly explained by the fact that also this event is human factor related and there is no special reason to distinguish from the previous case.

The annual frequency of the **K111 top event** resulting from the above values and assuming 26 missions per year is given in figure 1.3. This consists of the catastrophic rupture of the SO_2 tank wagon as a consequence of the impact with the alkali/chlorine.

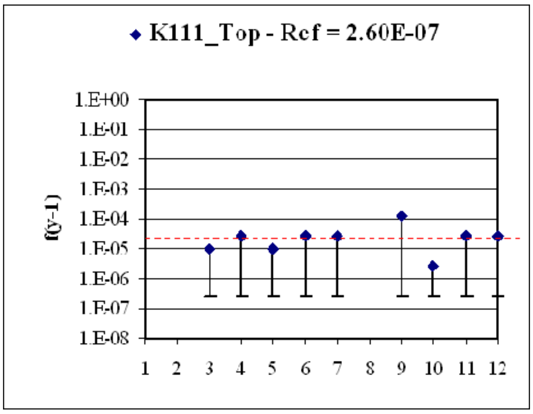


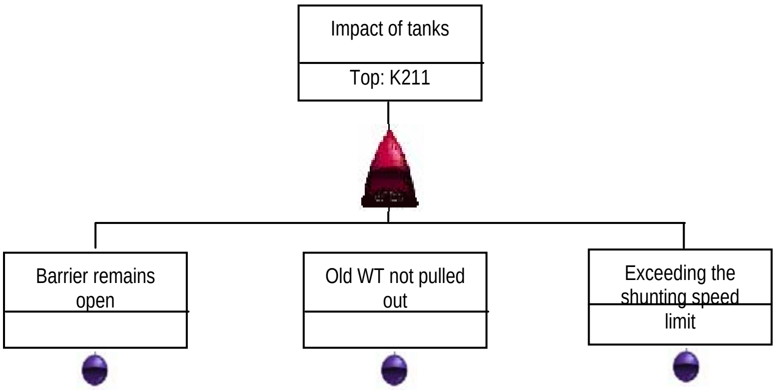
Figure 13: frequency of the top event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

In general the values perceived by the members for this top event ca. 2 orders of magnitude higher than the reference value (**median 2.6E-5, range: 2.6E-06 -1.3E-04**). This is obviously due to the different perception for the value of the K111_SL event.

Scenario K211

54 t SO_2 release to the environment as a consequence of the catastrophic rupture of the SO_2 tank wagon due to mechanical impact during wagon change.

The present Scenario is caused by human factors related events, for which the likelihood of occurrence is expressed through a probability (*q*) instead of a frequency. This Scenario is described by the fault-tree shown below:



The results of the review of the BEQUAR members on the probability values for the initiating events are shown in figures 14 and 15, which refer to the events K211_BAR and K211_OUT, respectively. K211_SL is simply equal to K111_SL and the previous figure 11 applies.

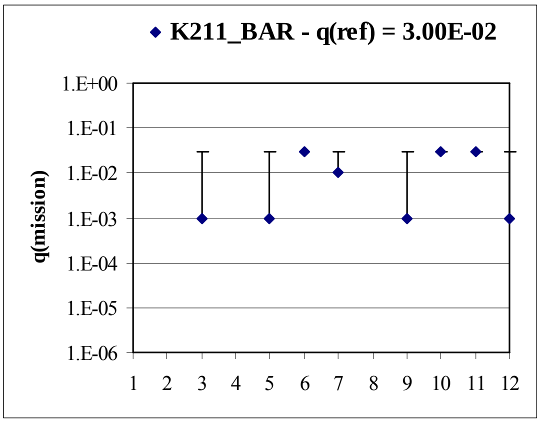


Figure 14: Likelihood of occurrence (per mission) of the K211_BAR event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

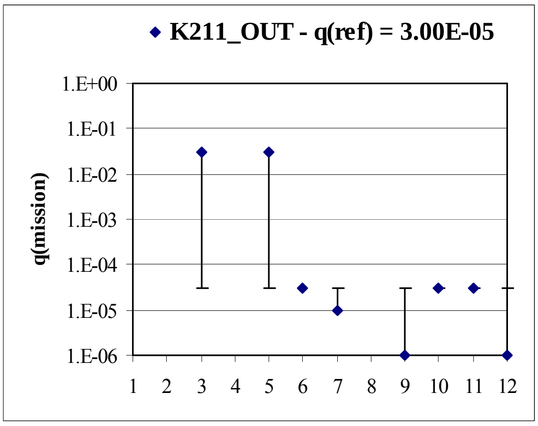


Figure 15: Likelihood of occurrence (per mission) of the K211_OUT event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

The BEQUAR group response as a whole is given in table 8 (median and range) and it is compared to the values taken as the reference and submitted to review.

Event	**Description**	**Type**	***q(ref)***	***q(median)***	***q(range)***

K211_BAR	*Operator fault: barrier remains open*	Basic	3.0E-02	5.5E-03	1.00E-03 3.00E-02
K211_OUT	*Fault in sequence of operation: wagon wasn't pulled out of tank*	Basic	3.0E-05	3.0E-05	1.00E-06 3.00E-02
K211_SL	*Exceeding the shunting speed limit (operator fault)*	Basic	1.0E-05	1.0E-3	1.00E-04 5.00E-03

Table 8

For the event associated to the possibility that *barriers remain open,* half of the responders were in agreement with the reference value whilst the remaining part considered it as less likely (ca. 1 decade lower). A large discrepancy was found with the event of *fault in the sequence operation,* as the proposed values scatter of about 4 orders of magnitude from each other.

The frequency of the **K211 top event** resulting from the above values and assuming 10 missions per year is given in figure 16. This consists of the catastrophic rupture of the SO_2 tank wagon during wagon change.

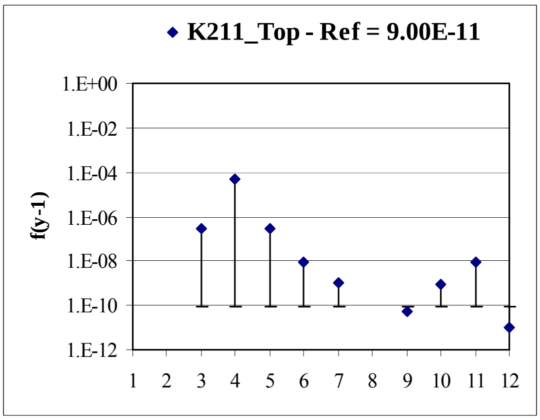


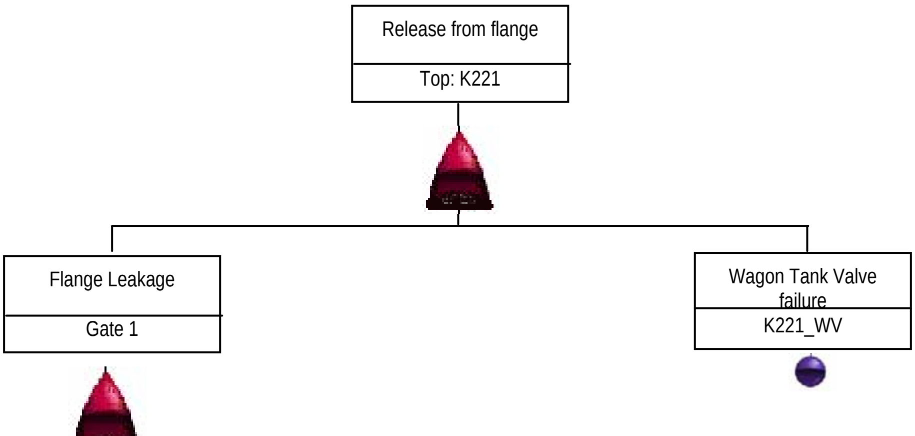
Figure 16: Frequency of the top event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

Also in this case the values perceived by the members are higher than the reference value (median: **9.00E-09** range: **1.00E-11 - 5.00E-05**).

Scenario K221

Not isolable leakage of due to failure of flange connection AND failure of tank wagon valve; vertical outflow from ø40 mm during 10 minutes (time required for mounting the shut-off valve)

The present Scenario is caused by human factors related events, for which the likelihood of occurrence is expressed through a probability (*q)* instead of a frequency. This Scenario is described by the fault-tree shown below:



The results of the review of the BEQUAR members on the probability values for the initiating events are shown in figures 17-19, which refer to the events K221_AF, K221_GF and K221_WV, respectively.

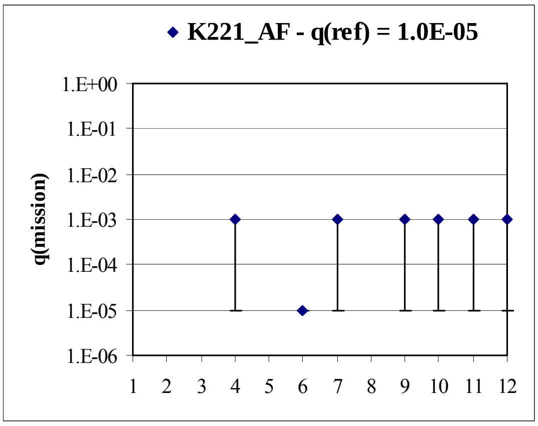


Figure 17: Likelihood of occurrence (per mission) of the K221_AF event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

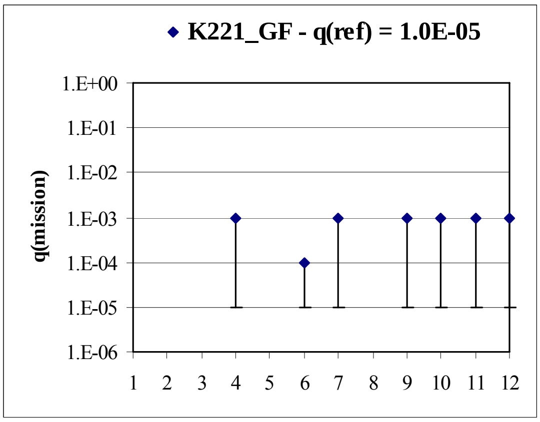


Figure 18: Likelihood of occurrence (per mission) of the K221_GF event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

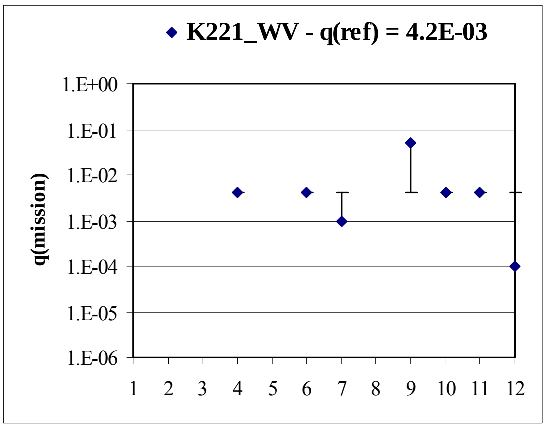


Figure 19: Likelihood of occurrence (per mission) of the K221_WV event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

The BEQUAR group response as a whole is given in table 9 (median and range) and it is compared to the values taken as the reference and submitted to review.

Event	**Description**	**Type**	***q(ref)***	***q(median)***	***q(range)***
K221_GF	*Human error: failed Gasket not properly checked*	Basic	1.0E-05	1.00E-03	1.00E-04 1.00E-03
K221_AF	*Human error on Flange adjustment*	Basic	1.0E-05	1.00E-03	1.00E-05 1.00E-03
K221_WV	*Tank Wagon valve failure*	Basic	4.2E-03	4.20E-03	1.00E-04 5.00E-02

Table 9

As for the previous cases, the main discrepancies were found on those human related events for which the reference likelihood of occurrence was estimated to be very low (ca. 1E-5). Specifically this conclusion refers to the failures of not *checking properly the gasket* (K211_GF) and the error in the *flange adjustment* (K221_AF). For these two events almost the totality of responders proposed values 2 decades higher.

For the human error related event consisting of the failure of *closing the tank valve* (K221_WV), the proposed value was considered as appropriate by 4 out of 7 responders. A reviewer (member n. 9) proposed to slightly modify the right side of the fault-tree to better describe the K221_WV event, by incorporating human error and component failure causes. The proposed value lied between 1E-02 and 1E-01 and it was argued that the release would make difficult the closing valve operation.

The annual frequency of the **K221 top event** resulting from the above values and assuming 10 missions per year is given in figure 20. This consists of a leakage from the flange due to a bad connection of the flange itself during wagon change.

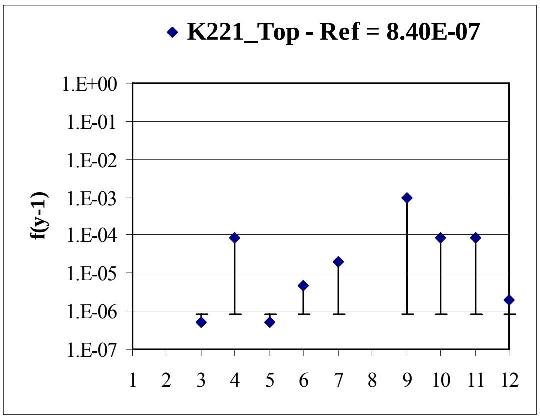


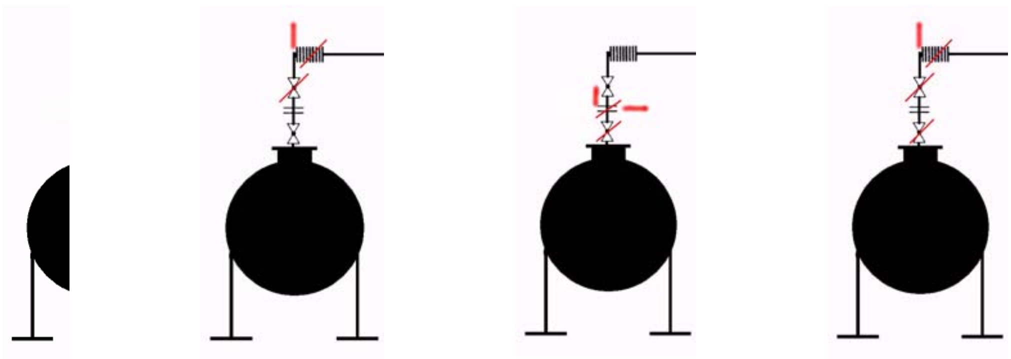
Figure 20: Frequency of the top event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

The values perceived by the reviewers were always higher than the reference (**median: 2.0E-05; range 5.0E-08-1.0E-03**). A point to note is that amongst the 3 members who agreed with the reference value, members 3 and 5 provided their assessment directly on the top event without giving information on the basic events.

<u>Scenarios: K121, K131, K151, K161</u>
The Scenarios of this section refer to the situation in which the sulphur dioxide tank wagon is on line. It was supposed that all components were working properly at the beginning of each mission (876 *h* duration).

The different Scenarios are illustrated in figure 21. The critical components that are cause of the initiating events are also shown in the figure.

All the Scenarios concerned are caused by failure of components. Their annual frequency can, therefore, be estimated from the component failure rate (**λ**). From the failure rate it is indeed possible to calculate the expected number of failures (w) for mission time and than multiply this value by the number of missions in a year (10).



K121
Isolable leakage

K131
Isolable leakage due to <u>flexible pipe</u> rupture AND failure of the <u>protection valve</u> (spring valve)

K151
Not Isolable leakage of equivalent ø10 mm due to failure of the <u>flange</u> AND the <u>tank wagon valve</u>

K161
Not Isolable leakage due to <u>flexible pipe</u> rupture AND failure of the <u>protection valve</u> (spring valve) AND <u>tank wagon</u>

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Figure 21: Scheme of the different Scenarios

The BEQUAR members were asked to review the data on failure rate of the involved components. The results of this review are given in figures 22, 23, and 24, which refer to: flange, flexible pipe, and protection valve, respectively. These figures reports the values as perceived by the different partners and are compared to the reference value (bar on the graph).

The failure of the tank wagon valve was considered as a human factor related event. Its review was presented in figure 19 of the previous section.

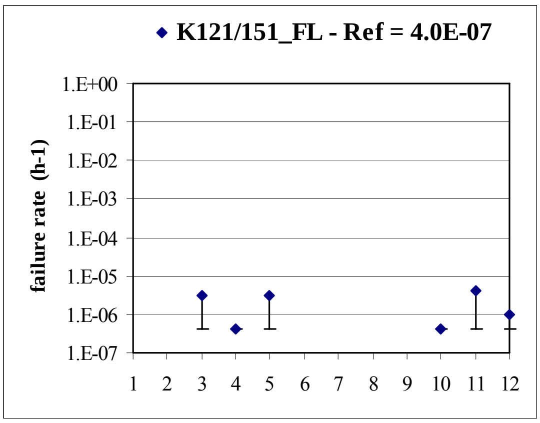

*Figure 22: Failure rate (per h-1) of the **flange** of Scenarios K121 and K151 as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value*

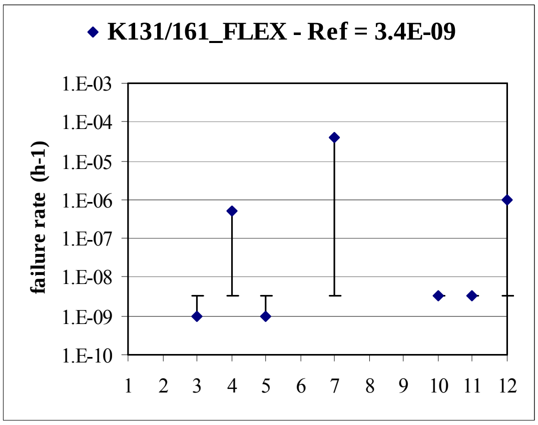

Figure 23: Failure rate (per h-1) of the ***flexible pipe*** *of Scenarios K131 and K161 as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value*

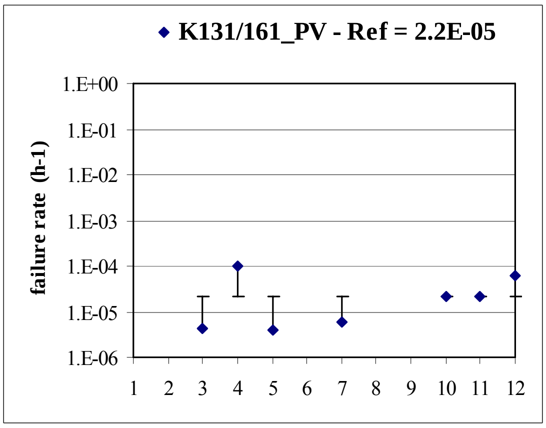

Figure 24: Failure rate (per h-1) of the ***protection valve (spring valve)*** *of Scenarios K131 and K161 as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value*

The BEQUAR group response as a whole is given in table 10 (median and range) and it is compared to the values taken as the reference and submitted to review.

Event	***Description***	***λ (h^{-1}) REF***	***λ (h^{-1}) Median***	***λ (h^{-1}) Range***
K121_FL K151_FL	*Flange leakage*	4.0E-07	2.0E-06	4.0E-07 4.0E-06
K131_FLEX K161_FLEX	*Flexible pipe rupture*	3.4E-09	3.40E-09	1.00E-09 4.00E-05
K131_PV K161_FL	*Protection valve failure*	2.2E-05	2.2E-05	4.00E-06 1.00E-04

Table 10

By observing the general trend, it could be noticed a quite limited spread of the data from the reference value for the *flange* and *protection valve* cases. In particular for the *flange* the values proposed (fig. 22) are normally higher than the reference (1 decade at most). For the *protection valve* (fig. 24) higher and lower values were proposed, but always within a decade extent.

For the *flexible pipe* (fig. 23) a much higher spread of data was noticed, for which 3 out of 7 reviewers proposed values exceeding at least 2 orders of magnitude if compared to the reference.

From the failure frequency values as provided by the BEQUAR reviewers, it was possible to calculate the corresponding probability of failure for mission time of the involved components through the following formula:

$$q = 1 - \exp(-\lambda \, t_M)$$

where t_M is the mission time (876 *h*).

Figures 25-27 gives the values of the probability of failure at the end of mission for the different components involved.

It should be noted that data provided by BEQUAR member 9 were also added. The member did not provide failure rate data but provided values of annual frequency. These values were then converted to frequency per mission time and included in figures 25-27. A good agreement with the reference value can be noticed, with the exception of the flexible pipe.

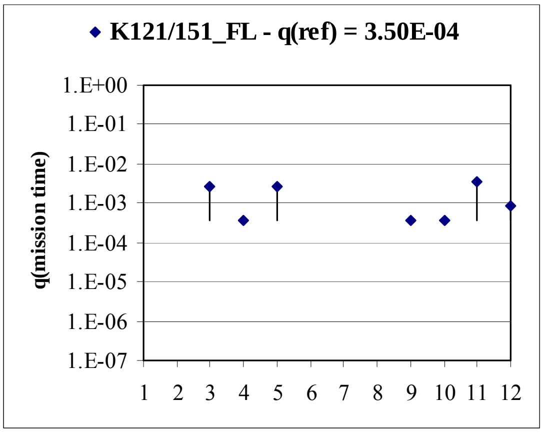

*Figure 25: Probability of failure per mission of the **flange** (Scenarios K121 and K151) as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value*

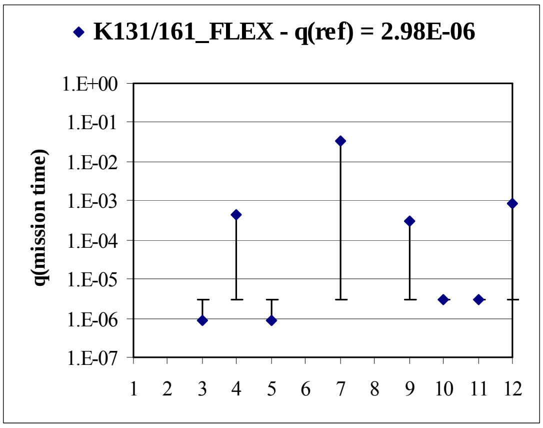

*Figure 26: Probability of failure per mission of the **flexible pipe** (Scenarios K131 and K161) as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value*

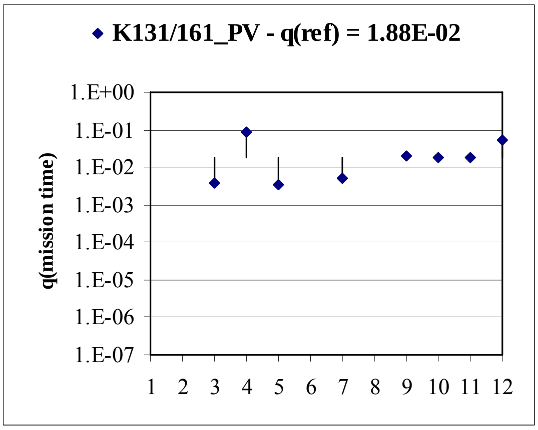

*Figure 27: Probability of failure per mission of the **protection valve** (Scenarios K131 and K161) as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value*

The following table summarises the results of the review:

Event	*Description*	*q (h-1) REF*	*q(h-1) Median*	*q (h-1) Range*
K121_FL K151_FL	*Flange leakage*	3.50E-04	8.76E-04	4.00E-06 3.50E-03
K131_FLEX K161_FLEX	*Flexible pipe rupture*	2.98E-06	3.20E-06	8.76E-07 3.44E-02
K131_PV K161_FL	*Protection valve failure*	1.88E-02	1.20E-02	2.28E-04 8.39E-02

Table 11

The annual frequency of the **top events of Scenarios K121, K131, K151, and K161**, resulting from the above values is given in figures 28-31.

As expected, Scenarios involving the failure of flexible pipe (K131 and K161) are those characterised by a larger spread. This is obviously due to the greater uncertainty on the data which refer to this component.

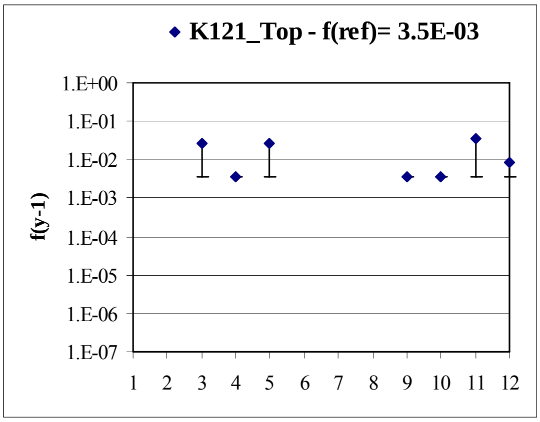

Figure 28: Annual frequency of the K121 top event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

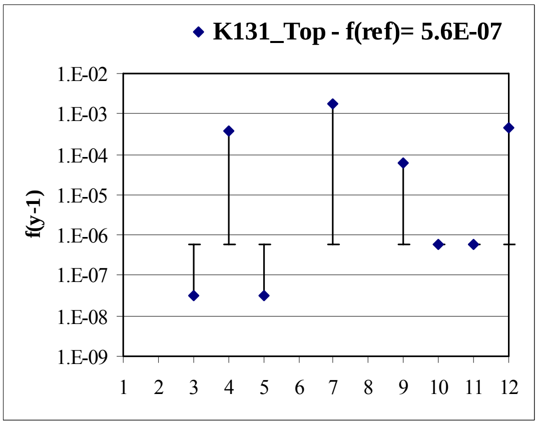

Figure 29: Annual frequency of the K131 top event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

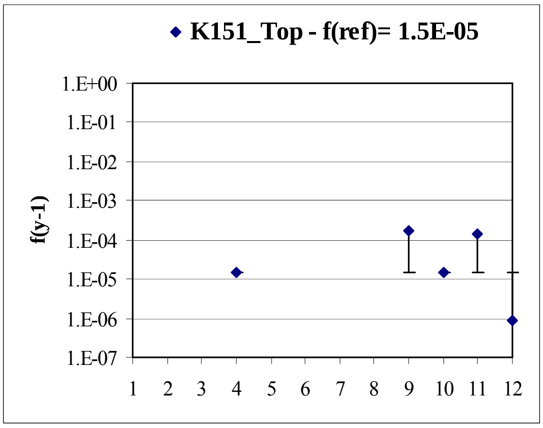

Figure 30: Annual frequency of the K151 top event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

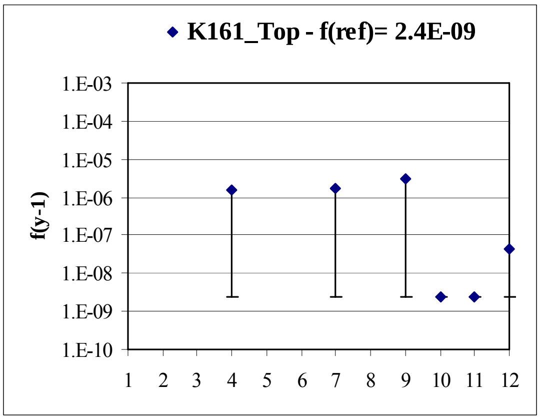

Figure 31: Annual frequency of the K161 top event as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

The following table summarise the global response of the BEQUAR members on top events:

Top Event	***f (y^{-1})*** ***REF***	***f(y^{-1})*** ***Median***	***f (y^{-1})*** ***Range***
K121	3.5E-03	8.76E-03	3.50E-03 3.50E-02
K131	5.6E-07	3.03E-05	3.06E-08 1.77E-03
K151	1.5E-05	1.47E-05	8.76E-07 1.75E-04
K161	2.4E-09	7.94E-07	2.36E-09 3.00E-06

Table 12

3.2 Ethanol related Scenarios

Scenario A11

Ethanol release due to catastrophic rupture of the tank.

In case of catastrophic rupture of the tank, the review of the annual frequency by the BEQUAR members is given in figure 32. The values are in agreement within a decade.

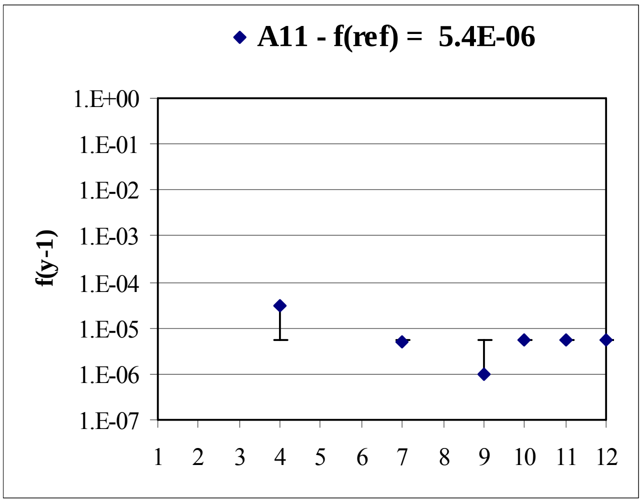

Figure 32: Annual frequency of A11 as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value.

Scenario A12

Ethanol release due to not isolable pipe rupture (ø80 mm)

In case of release by pipe rupture, the review of the annual frequency by the BEQUAR members is given in figure 33. The values are in agreement within a decade with the exception of the data provided by member n.4, who provided a value ca 4 orders of magnitude higher.

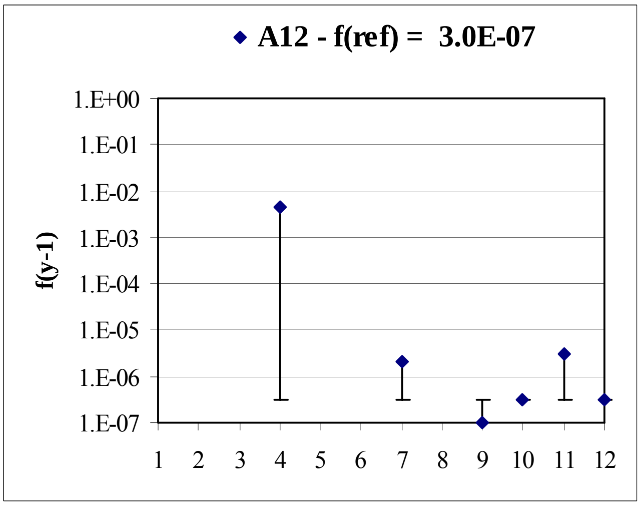

Figure 33: Annual frequency of A11 as perceived by the BEQUAR members. The bars on the graph represent the distance from the reference value

REVIEW OF THE CONSEQUENCE ASSESSMENT

1. INTRODUCTION

The present chapter summarises the main conclusions of the review on the reference establishment consequence assessment, which was conducted by the BEQUAR members. As usual, the reported analysis refers to the accident Scenarios postulated through the Hazard Identification Analysis.

The consequence assessment was completed by the JRC who played the role of the operator for this exercise. The analysis was conducted by employing the assumptions made by the operator of the actual plant but by using atmospheric data of the fictitious setting where the reference establishment was supposed to be located.

Due to the limited resources, it was decided to limit the review to some aspects of the consequence analysis only. In particular, the analysis of the damage curves as obtained through modelling of the toxic gas dispersion and/or pressure/temperature distributions were excluded from the evaluation exercise. This would have had required the availability of codes for modelling calculation that was not in possession of several BEQUAR participants.

By contrast, the review was carried out on:

- the conclusions of the 'source terms' calculation, which represent the input data for the calculation of damage curves.
- the vulnerability data (probit values & threshold limits)

2. SUMMARY OF THE RESULTS OF CONSEQUENCE ANALYSIS

The consequence analysis conducted for the specific purpose of this benchmark was conducted by the JRC with the technical assistance of the consultant who conducted the risk analysis of the actual plant and of another member of BEQUAR having a specific experience in the modelling used for damage assessment. This analysis are presented in separate documents[19,20].

The next sections contain the results of source terms' calculations, which were used for the consequence assessment. As damage curves were not submitted to review, the results of consequence assessment that relate to this calculation were not reported in the present document Detailed information on damage curves' calculations was reported in the previously quoted BEQUAR internal document[18].

Finally, the data used to assess the vulnerability are also reported.

2.1 Source Term' results: SO_2 related Scenarios

<u>Background/Assumptions</u>

The tank wagon full of SO_2 was modelled as a cylinder placed at 1.1 m *height* from the concrete surface, with a 3 m *diameter* and a 10.5 m *length* (see figure 34). The full tank contains 54 tons of liquid SO_2 in the saturated condition under temperature of 40º C, which is maintained by external water heating (saturated water with temperature 120ºC).

[19] BEQUAR Internal Document, Accident Consequence Analysis, CNS Rev. 2.0, Technical note , May 2005
[20] BEQUAR Internal Document, Probit parameters for the BEQUAR case study, VLN Data Rev. 2.0, Technical note , January 2006

Atmospheric data were imported from the JRC's meteorological service web[21,22]. Four different periods were taken in consideration and the data are shown in table 14. The fictitious location is in an industrial area highly populated with a *terrain roughness value* of Z = 0.17.

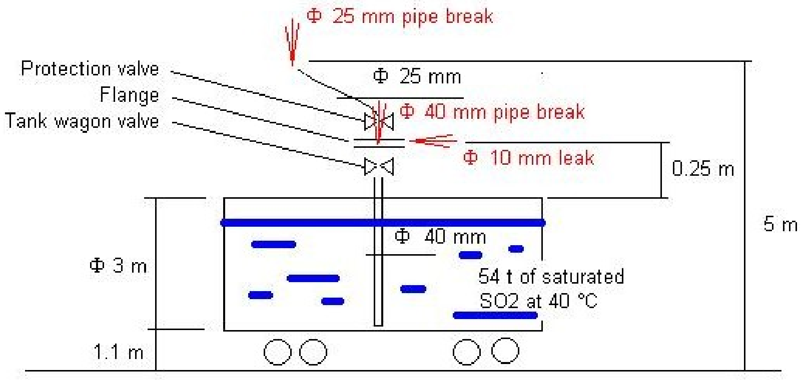

Figure 34: Schematic drawing of the tank wagon

	Air Temp, °C	Surface Temp, °C	Solar irr. flux, kW/m²	Pressure, bar	Relative humidity, %	Atm. Stability, Pasquill	Wind 10 m above ground, m/s
Winter – day	*6.4*	*6.1*	*0.6*	*1*	*73*	*B/C*	*3,2*
Winter – night	*3*	*4.8*	*0*	*1*	*84*	*F*	*2,3*
Summer – day	*27.1*	*27.3*	*0.7*	*1*	*67*	*B/C*	*3,6*
Summer – night	*14.3*	*16.5*	*0*	*1*	*79*	*F*	*2,3*

Table 13: Environmental parameters

The calculations presented in the following sections were carried out by using PHAST 6.42 (DNV Technica, Norway)[23] under the following assumptions:

- The backflow in the pipe bridge was neglected in each case as the target tank contains SO_2 in water solution and the content within the pipe bridge itself is negligible.
- The level of liquid within the tank wagon is always supposed to be above the submerged pipe end (see figure 34). This means that the outflow is always in liquid phase.

Material data were taken from the material data library available within PHAST.

<u>Scenario K111 Tank rupture</u>
Simulated as catastrophic rupture.
Result: Two-phase release of all content (54 t) of the wagon at once
<u>Scenario K121 Isolable leakage on the pipe, before the pipe failure protector valve</u>
Simulated as equivalent ø10 mm horizontal leak at the height of 4.35 m.
Result: Two-phase horizontal release with mass flow rate practically constant in time (ca. 1.8 kg/s – see next table), at the height of 4.35 m.

Mass flow rate, kg/s	Time, min.
1.83	0
1.82	16.5
1.81	32
1.80	49.5

[21] http://iamest.jrc.it/meteo/meteo.php
[22] http://re.jrc.cec.eu.int/pvgis/pv/imaps/imaps.htm
[23] http://www.dnv.com/software/all/phast/productInfo.asp

Table 14: Mass flow rate for the ø10 mm horizontal leak

Comment: The loss effect due to the submerged ø40 mm pipe has been neglected because the flow rate from a 40mm pipe is approximately (8.8 kg/s), which is much higher of the obtained values.

Scenario K131 Isolable leakage on the flexible pipe
Simulated as ø25 mm vertical outflow from the pipe of the length of 0.65 m at the height of 5 m.
Result: Two-phase vertical release with mass flow rate practically constant in time (3.9 kg/s – see next table), at the height of 5 m.

Mass flow rate, kg/s	Time, min.
3.93	0
3.90	7.6
3.87	15.3
3.84	23
3.81	31

Table 15: Vertical outflow mass flow rate from ø25 mm pipe

Comment: The loss effect due to the submerged ø40 mm pipe has been neglected because the flow rate from a 40mm pipe is approximately 8.8 kg/s, which is much higher of the obtained values.
Scenario K151 Not isolable leakage on the pipe, before the pipe failure protector valve
Simulated as Scenario K121, followed by ø40 mm vertical outflow from the pipe of the length of 3.25 m at the height of 4.35 m.
Result: Horizontal two-phase release with average mass flow rate of ca. 1.8 kg/s, for 20 or 30 minutes at the height of 4.35 m, followed by vertical two-phase release with mass flow rate of approximately 8.8 kg/s – see next table, for 10 minutes at the height of 4.35 m.

Mass flow rate, kg/s	Time, min.
8.9	0
8.85	3.4
8.8	6.75
8.75	10.2
8.7	13.6
8,65	17,0
8,60	20,5
8,55	24
8,50	27,5
8,45	31,0
8,40	34,6

Table 16: Vertical outflow mass flow rate from ø40 mm pipe

Scenario K161 Not Isolable leakage on the flexible pipe
Simulated as Scenario K131, followed by ø40 mm vertical outflow from the pipe of the length of 3.25 m at the height of 4.35 m.
Result: Two-phase vertical release with mass flow rate of approximately 3.9 kg/s, for 20 or 30 minutes at the height of 5 m, followed by vertical two-phase release with mass flow rate 8.8 kg/s, for 10 minutes at the height of 4.35 m.

Scenario K211 Tank rupture
Simulated as Scenario K111.

Result: Two-phase release of all content (54 t) of the wagon at once

Scenario K221 Not isolable release before the shut-off valve line
Simulated as Scenario K151.
Result: Horizontal two-phase release with mass flow rate approximately 1.81 kg/s, for 20 or 30 minutes at the height of 4.35 m, followed by vertical two-phase release with mass flow rate 8.8 kg/s, for 10 minutes at the height of 4.35 m.

2.2 Source Terms' results: Ethanol related Scenarios

Background/Assumptions
The ethanol storage concrete tanks of cylindrical shape with different dimensions were supposed to be 100% full of liquid ethanol under environmental conditions. The tanks stand on the ground inside a concrete bund. Temperature was supposed to be maintained through external water-cooling by 20.1°C during hot summer time. Fire and explosion consequences of the material were simulated. The results showed that evaporation from the pool in the bund after a possible accident is very low and only pool fire is of practical importance. As a matter of fact ethanol has normal boiling point at 78-79ºC, with flash point at 13ºC.

It is reminded that the involved Scenarios were of two types:
- Scenario A11_*x*: catastrophic rupture of tank N. *x*
- Scenario A12_*x* : tank drainage nozzle rupture ø80mm on the tank N. *x*

The backflow in the pipe bridge was neglected for Scenarios A12_*x*, as the backflow prevention valve is supposed to work correctly.

All catastrophic rupture Scenarios - A11_1 – A11_10
Simulated as catastrophic rupture.
Result: Spray release of all content at once with immediate rain-out of droplets. All material is contained in the bund.

A12_1 Tank drainage nozzle rupture ø80mm on the tank No. 1
Simulated as horizontal leak ø80mm.
Result: Liquid release with variable rate – see next figure. Average rate for consequence analysis taken is 24,21 kg/s. The outflow time is 72 hours. All material is contained in the bund.

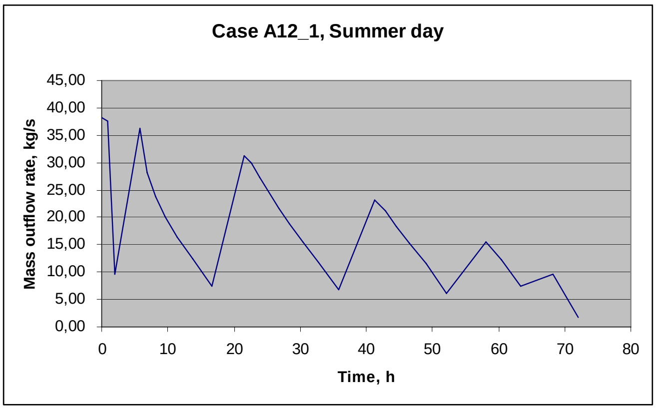

Figure 35: Tank outflow rate for the A12_1 case: Summer day

A12_2 Tank drainage nozzle rupture ø80mm on the tank No. 2
Simulated as horizontal leak ø80mm.
Result: Liquid release with variable rate – see next figure. Average outflow rate for consequence analysis used is 19,57 kg/s. The outflow time is 35 hours. All material is contained in the bund.

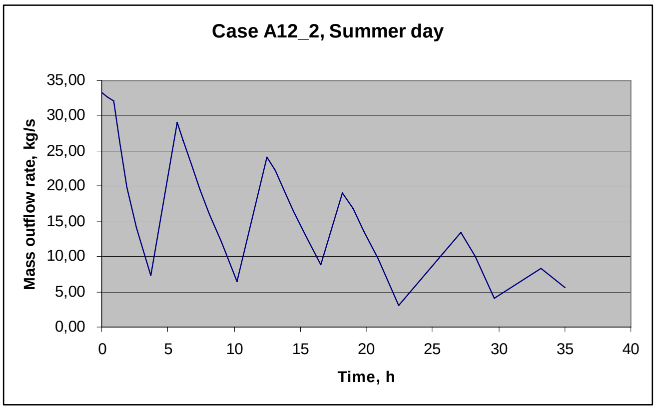

Figure 36: Tank outflow rate for the A12_2 case: Summer day

<u>A12_3 Tank drainage nozzle rupture ø80mm on the tank No. 3</u>
Simulated as horizontal leak ø 80mm.
Result: Liquid release with variable rate – see next figure. Average outflow mass rate taken for consequence analysis is 15,69 kg/s. The outflow time is 20 hours. All material is contained in the bund.

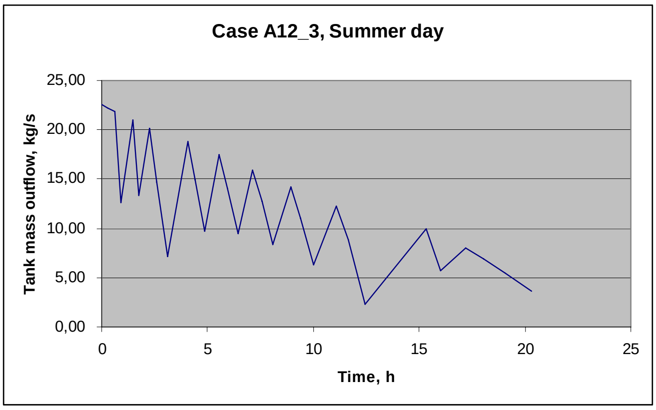

Figure 37: Tank mass outflow rate for the case A12_3: Summer day

<u>A12_6/7 Tank drainage nozzle rupture ø80mm on the tank No. 6/7</u>
Simulated as horizontal leak ø 80mm.
Result: Liquid release with variable rate – see next figure. Average outflow rate taken for consequence analysis is 17,96 kg/s. Time to full outflow is 11,23 hours. All material is contained in the bund.

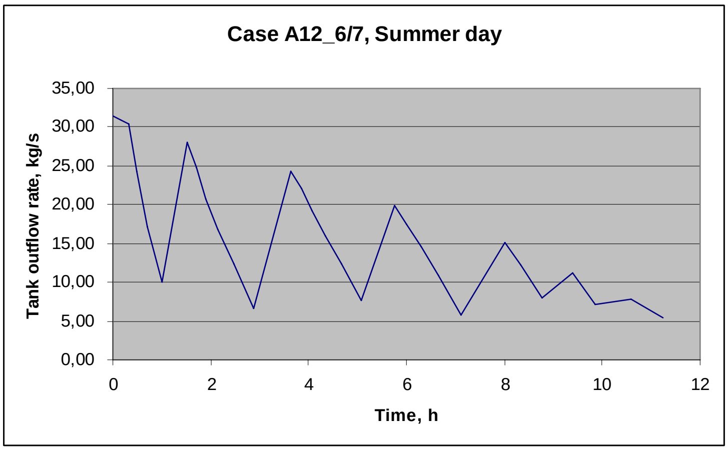

Figure 38: Tank outflow rate for the case A12_6/7, Summer day

A12_10 Tank drainage nozzle rupture ø80mm on the tank No. 10
Simulated as horizontal leak ø80mm.
Result: Liquid release with variable rate – see Figure 39. Average outflow rate taken for consequence analysis is 14,58 kg/s. Time to full outflow is 3,43 hours. All material is contained in the bund.

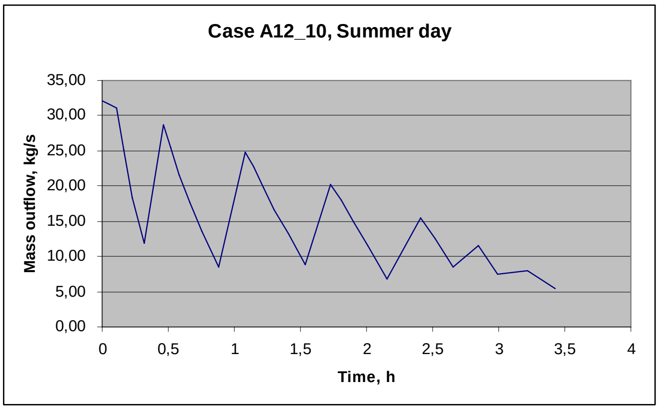

Figure 39: Mass outflow for the case A12_10, Summer day

2.3 Vulnerability data

In the study of consequence assessment, the last logical step to be covered is usually the estimate of the consequences on the man and the environment. Once the modelling of the accidents' effects (thermal radiation, pressure wave, evolution of the concentration in the atmosphere) have been completed, the conversion of these results to the consequences is required. This can be done by the so-called "vulnerability analysis". In order to estimate consequences of an accident on humans, a function relating the magnitude of the impact, e.g. the thermal radiation from a fire, with the extent of damage caused by accident is required; i.e., a relationship between the dose and the response must be defined. Usually for the QRA purposes, the method used is the analysis based on Probit functions. In other cases the analysis is concluded by the assessment of the safety distances only. In these cases, the concentration field is compared to threshold limits (i.e. a limit on a measurable quantity, established or formally accepted by a regulatory body).

The following table describes the alternative vulnerability parameters which were used in the benchmark. The data represented in bold are those used as the reference values in the risk analysis:

Probit estimation		*Safety limit values*	
Effect type	Probit equation (lethality)	Effect type	Acceptable threshold values
Heat radiation	*-38,48+2,56ln($t_{Exposure}$[s].Heat intensity [W/m^2]$^{4/3}$) [24]*	Heat radiation	*2kW/m^2 - 2nd degree burns in 20 s [25]*
	-14,9+2,56ln($t_{Exposure}$.Heat intensity$^{4/3}$) [26]		*12,5kW/m^2 - 2nd degree burns in 20 s [27]*

24 Phast 6.42 documentation, Det Norske Veritas, 2004
25 B.R. Williamson, L.R.B. Mann, "Thermal hazards from propane (LPG) fireballs," Combust. Sci. Tech., vol. 25, 1981, p. 141
26 F.P. Lees, "Loss Prevention in the Process Industries," 2nd ed., Butterworth-Heinemann, Oxford, UK, 1980
27 Rijnmond Public Authority (1982). A Risk Analysis of 6 Potentially Hazardous Industrial Objects in the Rijnmond Area-A Pilot Study. D. Reidel, Dordrecht, The Netherlands and Boston, MA. (ISBN 90-277-1393-6)

	-36,38+2,56ln($t_{Exposure}$.Heat intensity$^{4/3}$) [28]		*35 kW/m^2 for 20 s - 50% fatality [29]*
	-39,83+3,0186ln($t_{exposure}$.Heat intensity4/3) [32]		
Explosion blast wave	*5-5,74ln{f(PeakOverpressure, p_{atm},BodyWeight} [28]*	Explosion blast wave	*2,4-3,1 bar – 1% fatality [30]*
	-77,1+6,91ln(PeakOverpressure [Pa]) []		*1 bar – 1% fatality [31]*
SO_2 toxicity	*-16,89+ln(Concentration^{2,4} [ppm]. $t_{Exposure}$ [min]) [24]*	SO_2 toxicity	*ERPG-2*
	-17,73+2,1ln(Concentration[mg/m^3].$t_{Exposure}$ min]) []		
	-27,9+1,14ln(Concentration^{3,7} [mg/m^3]$t_{Exposure}$ [min]) []		*IDLH*
	-15,67+2,1ln(Concentration[ppm]. $t_{Exposure}$ [min]) [32]		

Table 17: vulnerability data used for BEQUAR. The data indicated in bold are those considered as reference values for this exercise and used for the risk analysis phase

Toxicity

The problem of the usage of probit functions for toxics is that, for majority of substances encountered in industry, there are not enough data on toxic responses of humans to directly determine a substance's hazard potential. Often, the only data available are from controlled experiments conducted on laboratory animals. In these cases, it is necessary to extrapolate from the effects observed in animals to effects likely to occur in humans. This extrapolation introduces great uncertainty. Also, many releases involve several chemical components or multiple effects. At this time the cumulative effects of simultaneous exposure to more than one material is not well understood. Finally, there is no standardised toxicology testing protocols that exist for studying episodic releases on animals. There are experimental problems associated with the testing of toxic chemicals at high concentrations for very short durations in establishing the concentration/timer profile.

Generally there are two main sources of data, which are characterised by significant differences. One source of information is based on material-specific studies [ref 32 of previous page], the other one is based on the use of a generalised extrapolation scheme [ref 28 of previous page]. The difference between the available formulas could be significant as also shown in Table 17, and could lead to a significant difference in prediction of the extent of the effects of toxic release.

Concerning the usage of the safety limits, there is also a quite large spread of data in the literature. The data reported in Table 17 lead to safety distances which differ in an order of magnitude.

Blast effects.

Concerning the blast effects to humans the two main sources of Probit were taken into account for the present analysis.

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28 Methods for determination of possible damage to people and objects resulting from releases of hazardous material, CPR 16E, 1st edition, TNO, Voorburg, 1992

29 S. Mannan, "Lees's Loss Prevention in the Process Industries," 3rd ed., Elsevier Butterworth-Heinemann, Oxford, UK, 2005

30 S. Glasstone, "The effects of nuclear weapons," AS AEC, Washington, 1962

31 N.A. Eisenberg at al., "Vulnerability model," Nat. Tech. Int. Service Report AD-A015-245, Springfield, Va, 1975

32 Guidelines for Process Quantitative Risk Analysis, CCPS of AIChE, N. York, 1999

Heat radiation effects.

There are several probit equations that describe the relation between thermal radiation dosage and fatalities (see Table 17). Also in this case the differences are significant. Concerning the usage of the safety distances, there is also spread of acceptable values.

3. REVIEW OF THE SOURCE TERMS' DATA

The source terms' results were submitted to the BEQUAR members for discussion and review. Amongst the eight responders, different approaches were followed for justifying their argumentations. In particular, some assessed the results qualitatively whilst others followed a more quantitative approach.

The review was conducted by the BEQUAR responders through their reply to a questionnaire prepared by the JRC for this purpose. Detailed discussions followed during a project meeting.

3.1 Reaction and repair time

The reaction time after release is the time required to settle the problem and to intervene for stopping the release. The reference values submitted to the reviewers were **20 min** and **30 min**, in the cases in which the gas detection sensors are present or not, respectively. For some specific Scenarios (i.e., K151 and K161) associated to not isolable release (e.g. by closing a valve) some additional time to repair the component failure is required. During this action the opening of the flange is necessary, which is associated to an additional horizontal release of toxic gas. The reference value provided by the operator is **10 min**.

As a result of the consequence assessment study previously quoted[18], t, which the reaction time after release from the SO_2 tank do not seem to affect significantly the concentration curve of toxics. However the time of exposure and, in turn, the absorbed dose will definitely depend on this reaction time.

The BEQUAR reviewers were asked about their perception on the most suitable reaction time to be considered for the SO_2 related Scenarios with the exception of the catastrophic releases. The results are shown in the figures 35 and 36 that represent the different situations in which the detection sensors are present or not present, respectively.

In both cases ca. 50% of the reviewers tend to prefer more conservative values.

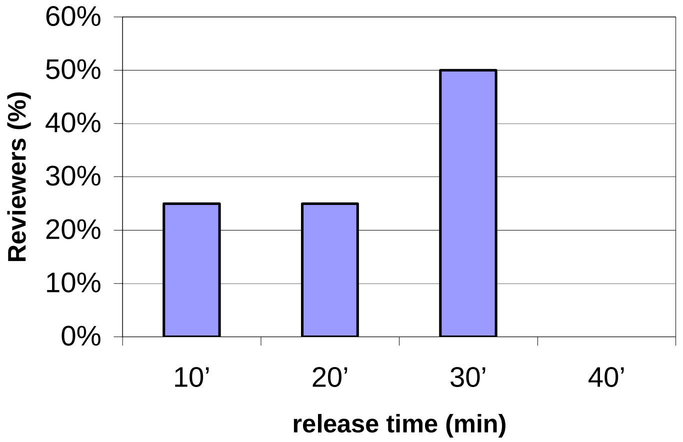


Figure 40: BEQUAR review on the reaction time after release in the case: ***"sensors present"***

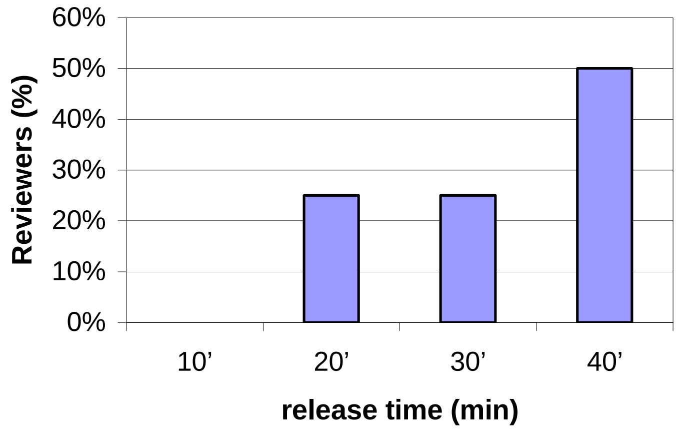


Figure 41: BEQUAR review on the reaction time after release in the case: ***"sensors not -present"***

With regard to the repair time, the reviewers were asked about their perception on the acceptability of the value provided by the operator. The reference value of 10 minutes was considered as very optimistic by the majority of the responders (see next figure). It was suggested the need to conduct some specific sensitivity studies on this aspect and it was mentioned that also some different meteorological conditions might influence the repairing activity (a rainy weather can transform into aerosols the sulphur dioxide and increased the toxicity).

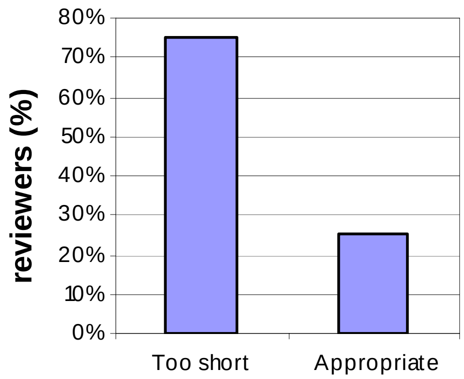


Figure 42: Acceptability of the repair time provided by the operator (10 min)

3.2 Source terms

<u>SO_2 related Scenarios</u>

Figure 43 shows the response of the BEQUAR reviewers in relation to the acceptability of the source terms' data presented in the previous chapter. For all the selected Scenarios the totality of responders considered the calculation as acceptable by responding 'to agree' on the final result.

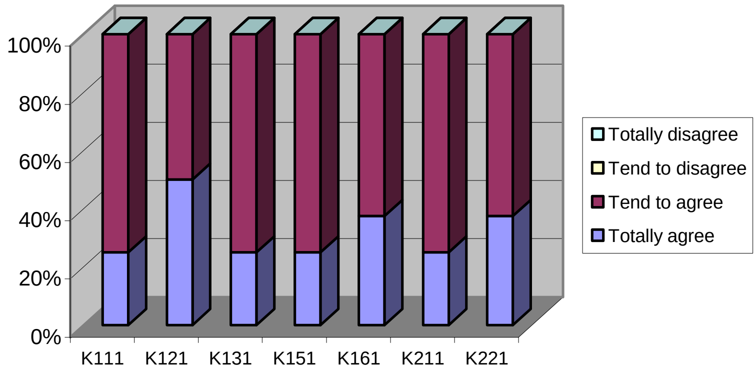


Figure 43: Source term calculations: acceptability by the BEQUAR reviewers (for SO_2)

Ethanol related Scenarios

Also for Ethanol, the majority of responders considered the source terms' calculations as acceptable (see Figure 44). However a few declared to disagree on the final results by using the following argumentation:

- Difficulty in the judgment due to a not totally clear description of Scenarios A11_1 - A11_10
- Anomalous behaviour of outflow rate in all Ethanol Scenarios
- Overestimated distance to 0,02 bar overpressure from all Ethanol explosions

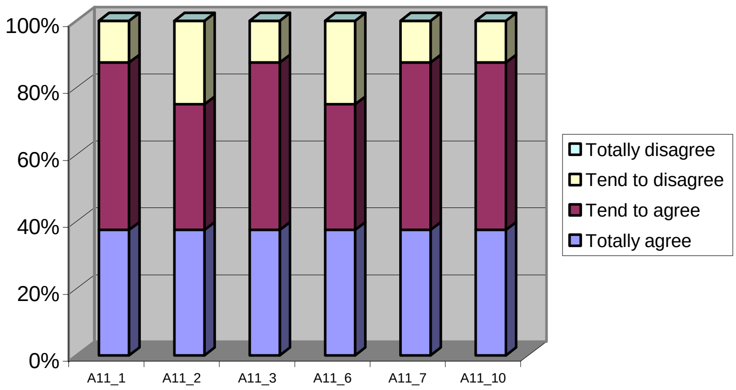


Figure 44: Source term calculations: acceptability by the BEQUAR reviewers (for Ethanol)

General observations during the meeting

In general the review showed that that for some countries, the worst-case Scenario (catastrophic rupture) is the only actually required for full evaluation. In others there is still the requirement for extending the analysis to all selected Scenarios, and in general the operator is entitled to select the methodology to be used. As a general comment it was established that no common methodology for consequence analysis is available/required in the new Member States. There is a clear understanding that a possible guidance in this filed would be more than welcomed.

4. REVIEW OF THE VULNERABILITY DATA

Nine of the BEQUAR members provided their review of the vulnerability data set. In particular they were asked to mark the *probit* formulas or the threshold values that they would consider as acceptable. The results of their choices is summarised in tables 18-19 and in figures 45-47.

To be noted that multiple marks were permitted, therefore, the number of marks for each category do not necessarily correspond to the number of responders.

Probit estimation		
Effect type	**Probit equation (lethality)**	**BEQUAR response**
SO2 toxicity	*-16,89+ln(Concentration[ppm]. tExposure [min]2,4) [DNV Technica, 2004]*	*3 marks*
	-17,73+2,1ln(Concentration[mg/m3]. tExposure [min]) [CPR 16E, TNO, 1992]	*3 marks*
	-27,9+1,14ln(Concentration[mg/m3]. tExposure [min]3,7) [CPR 16E, TNO, 1992]	*1 marks*
	-15,67+2,1ln(Concentration[mg/m3]. tExposure [min]) [CCPS Guidelines, 1999]	*2 marks*
Heat radiation	*-38,48+2,56ln(tExposure[s].Heat intensity [W/m2]4/3) [DNV Technica, 2004]*	*4 marks*
	-14,9+2,56ln(10-4.tExposure.Heat intensity4/3) [Lees, 1980]	*1 marks*
	-36,38+2,56ln(tExposure.Heat intensity4/3) [CPR 16E, TNO, 1992]	*4 marks*
	-39,83+3,0186ln(tExposure.Heat intensity4/3) [AichE, 1999]	*2 marks*
Explosion blast wave	*5-5,74ln{f(PeakOverpressure, patm, BodyWeight} [CPR 16E, TNO, 1992]*	*5 marks*
	-77,1+6,91ln(PeakOverpressure [Pa]) [Lees, 1980]	*2 marks*
	Other.	*0 marks*

Table 18: Preferences of the BEQUAR reviewers for the different proposed probit formulas

Threshold limits		
Effect type	**Acceptable threshold values**	**BEQUAR response**
SO2 toxicity	*ERPG-2 (3 ppm)*	*4 marks*
	EEL	*0 marks*
	IDLH (100 ppm)	*5 marks*
	Other (describe).	*0 marks*
Heat radiation	*2kW/m2 - 2nd degree burns in 20 s [Williamson&Mann, 1981]*	*0 marks*
	12,5kW/m2 - 2nd degree burns in 20 s [Rijnmond study, 1982]	*3 marks*
	35 kW/m2 for 20 s - 50% fatality [Mannan, 2005]	*3 marks*
	Other values proposed by the BEQUAR members (4,7 kW/m2, 5 kW/m2, 3 kW/m2)	*3 marks*
Explosion blast wave	*2,4-3,1 bar – 1% fatality [Glasstone, 1962]*	*0 marks*
	1 bar – 1% fatality [Eisenberg, 1975]	*6 marks*
	0,14 bar	*1 marks*

Table 19: Preferences of the BEQUAR reviewers for the different proposed threshold limits

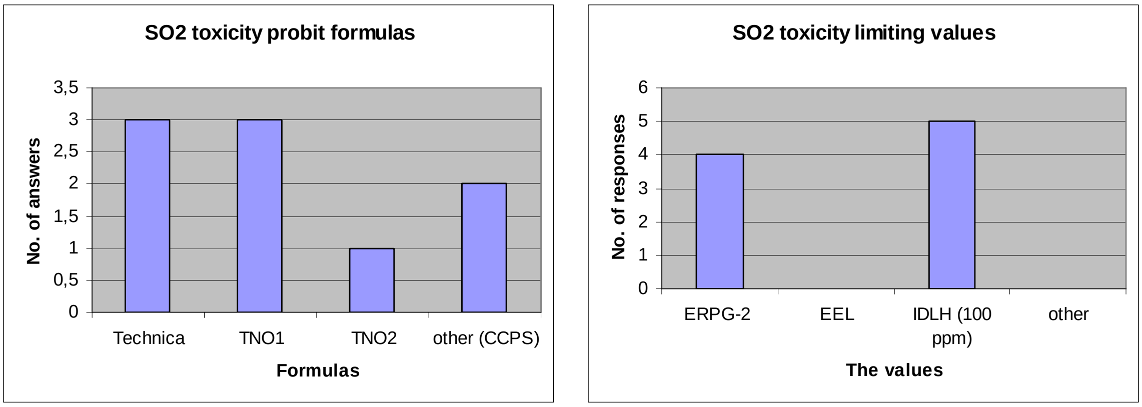


Figure 45: SO_2 toxicity effects: preferences of the BEQUAR reviewers for the different proposed probit formulas & threshold values

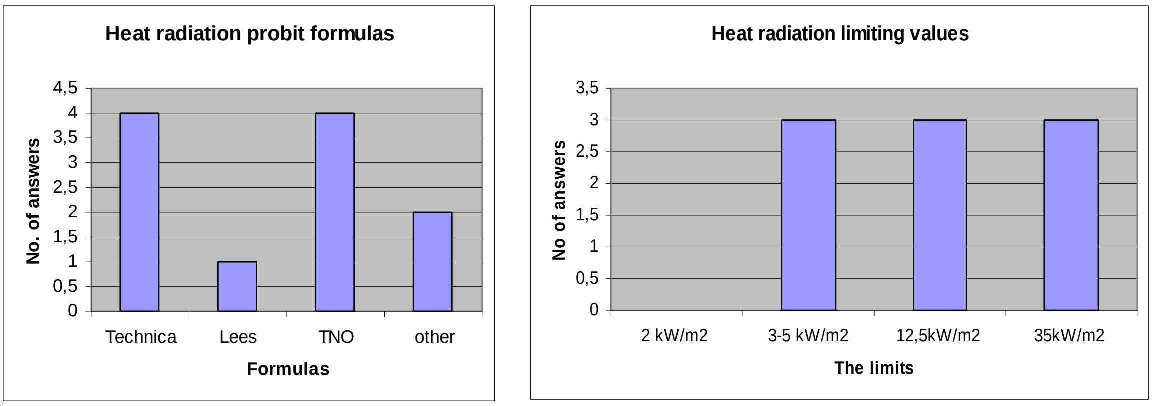


Figure 46: Heat radiation effects: preferences of the BEQUAR reviewers for the different proposed probit formulas & threshold values

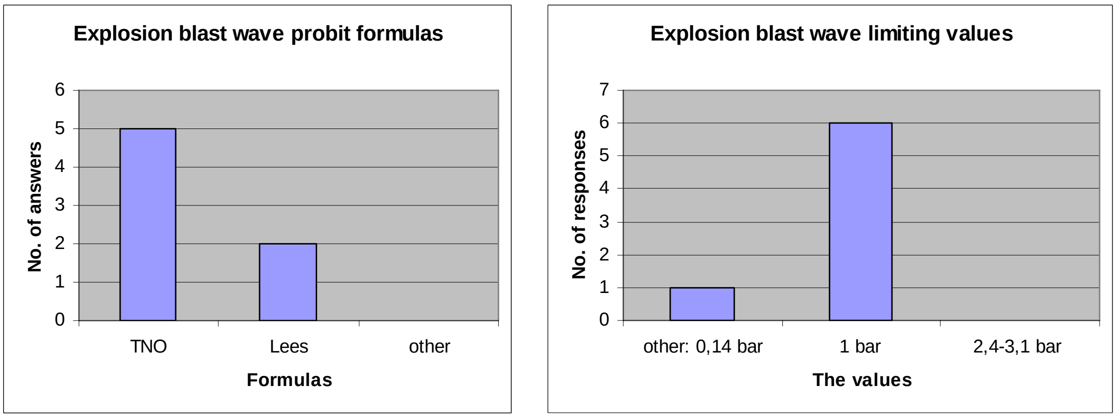


Figure 47: Blast wave overpressure: preferences of the BEQUAR reviewers for the different proposed probit formulas & threshold values

For toxic related parameters, it is quite evident the BEQUAR responders did not show any specific preference for the proposed *probit* formulas. The same can be stated for threshold limits. During the discussions that took place at the M3 meeting (Ispra 30-31 January, 2006) it was commonly agreed that in general any of the presented values and formulas have the right to be considered as acceptable for safety report purposes. As a matter of fact it is very difficult to assess which of the available formulas is more reliable. For this reason, a case by case approach should be followed depending on the potential impact of each single Scenario and the assumptions made (e.g., release times). It was however argued that at present the choice on the specific *probit* formulas to be used is often driven by practical reasons i.e. their availability in the literature or in the web, free of charge (e.g. US EPA's Aloha and TNO's books). In this sense all BEQUAR members supported the concept that the European Commission should drive an action oriented to collect and validate this type of data for risk analysis applications.

For heat radiation a quite spread of responses was noticed. For *probit,* all the proposed formulas received some attention, although TNO and DNV received the maximum scoring. The threshold limits selected by the different responders also varied quite significantly. Some of the BEQUAR reviewers proposed also some alternative values (4,7 kW/m^2, 5 kW/m^2, 3 kW/m^2)

For overpressure related Scenarios, the *probit* formula of TNO was definitely the preferred. As a threshold limit 1 bar was estimated to be the blast wave effect limit for almost the totality of responders.

4.1 Summary of the vulnerability analysis review

In general, the proposed formulas and values were considered as acceptable by the BEQUAR reviewers and it was not possible to detect any difference in the approaches followed in the different countries.

The general impression from the comments and discussions was that the position of the competent authorities in the newly associated Member States is in line with what it is generally accepted in the other countries.

The main outcome of this review and the following discussions is that, in general, no common methodology for consequence analysis is strictly required in the newly associated Member States.

There is a clear understanding that a possible guidance in this filed would be more than welcomed. Also the availability of codes for modelling calculation is not broadly available. This was is further impediment for the competent authorities in their daily supervising activity.

REVIEW OF THE ANALYSIS OF RISKS AND AREA RISK ANALYSIS

1. INTRODUCTION

The present chapter is addressed to analyse the impact of the different reviews conducted by the BEQUAR members on the overall risk analysis of the reference establishment and, in turn, on the area risk assessment.

The reference risk analysis was conducted by the JRC who played the role of the operator for this exercise. This analysis was conducted by re-elaborating some of the original data, assumptions and calculations available on the original safety report of the reference plant as described in the previous chapter. These were then used as input data for ARIPAR, which was used to produce the reference risk analysis outcome. As previously highlighted, the difference from the original data set, assumption, calculations and risk assessment methods, made the review of the reference risk analysis fully independent of the actual case. This guarantees the full non addressability of the conclusions of this study to the actual plant and associated surroundings used for this exercise.

The impact of the reviews on the risks of the reference establishment and the overall area risk was analysed through ARIPAR by using the input risk analysis data (source terms, frequency data, and vulnerability models) reviewed by each BEQUAR members.

2. SUMMARY OF THE RESULTS OF THE RISK OF THE REFERENCE PLANT

2.1 Methodology

The analysis of risks associated to the reference establishment was conducted in quantitative terms by using the ARIPAR methodology. The risk quantification procedure was carried out by aggregating all the risks associated to the different hazardous sources. All separate accident Scenarios described in the previous sections together with their occurrence frequencies and consequences (measured in terms of number of casualties) were taken into account for the calculation.

In order to represent the outcome of the analysis the following indicators were calculated:

i. *Local risk*: i.e. the expected frequency of the reference damage (death of people) occurring as a consequence of any accident, to a person who is permanently occupying (24 hours a day for one year) a certain point of the area, with no possibility of being sheltered or evacuated. It is a figure useful for characterising the risk in a given location. In ARIPAR the local risk has two types of representation, as risk contours, on the overall geographic area, and as a histogram showing, for a given location x, y, the risk value and the contribution of the different risk sources.

ii. The *Societal Risk* which addresses the number of people who might be affected by the accident. A *F-N* curve is a plot of the inverse cumulative frequency (*F*) of accidents from all the different sources capable of causing the reference damage to a number of people greater than or equal to *N*. The *F-N* curve is a figure useful for characterising the societal consequences of possible accidents. The frequency *F* naturally decreases as the number of fatalities increase. The limits of risk acceptability are shown as two parallel straight lines on the same diagram, with an area between them in which reduction is desirable.

The first step of the process was the identification of the impact area, i.e. the geographical area within which the consequences of potential accidents had to be studied. The extension of the impact area was selected on the basis of considerations about the a-priori judgement of the impact of potential accidents on the population as a whole. As already stated in a previous chapter, the environmental setting of the reference plant was intentionally modified to ensure anonymity. In particular, the exercise was conducted by assuming that the reference plant was based in a completely different location characterised by different local vulnerability, population density and distribution, and different weather conditions.

The analysis of risks was conducted by following the main steps described hereunder:

A. Description of the geographical area of interest
The first step was the definition of the source area, where the risk sources are located, and of the impact area, where the risk has to be determined. The impact area must be described by means of territorial data e.g. population density, high vulnerability resorts, transport networks. In addition, the risk analysis was performed by considering the solar year as reference time period. Since both the meteorological conditions and the population distribution vary with time, the whole year was subdivided into separate periods in which both the meteorological data and the population distribution can be considered constant with an acceptable degree of approximation. In the present case two separate periods were considered: (*i*) Summer-Spring and (*ii*) Winter-Autumn

B. Identification and inventory of accident risk sources
Storage, process plants and transport of dangerous substances define the risk sources, which exist on a territory where residents, workers and tourist live and could be subject to the potential consequences of an accident. The data collection has to be carried out with particular care and it represents therefore one of the most expensive phases. Data related to stored, processed and transported dangerous substances are collected in order to gain a detailed knowledge of annual flows and preferential courses in the impact area, besides giving the basic inputs for the accident frequency evaluation.

C. The off-line analysis of all accident Scenarios of interest
This includes identification and evaluation of likely accident Scenarios (gas dispersion, fire and explosion events, their probabilities and consequences) for each fixed installation and each type of transport. Generally this is another time consuming phase of the project because complex industrial realities must be analysed and accident typologies and frequencies in transport characterised.

D. The area risk assessment
The above mentioned measures of local, individual and societal risk are used as indicators of the area risk resulting from the merging of point risk sources (plants) and linear risk sources (different ways of transport).

The ARIPAR methodology uses a powerful numerical procedure able to overcome computational difficulties arising from:

- the non symmetric distribution of local and individual risk around sources, when Scenarios depending on wind rose must be simulated;
- the need to manage a large number of accident Scenarios;
- the presence of linear risk sources, caused by accidents travelling with vehicles (trucks, trains, ships) or with mass flows (in pipelines), which must be represented by many point sources (segments of fixed lengths).

Values of local and individual risk are calculated for the centres of the cells of a non regular grid superimposed to the impact area. At the same points the distributed population is clustered for societal risk evaluation purposes, so that an accurate choice of cells dimension

must be done to assure a good compromise between accuracy of results and acceptable computation time.
Time saving is also the aim of interpolation functions through which accident consequences are modelled. The results of each single accidental Scenario, available from numerical codes for discrete points only, are substituted by continuous functions representing the time and/or spatial distribution of concentrations, over pressures and thermal radiation.

2.2 Input data

Introduction

As for any risk analysis tool, ARIPAR requires the use of some general parameters which are specifically associated to the environmental setting which refer to the following subcategories:

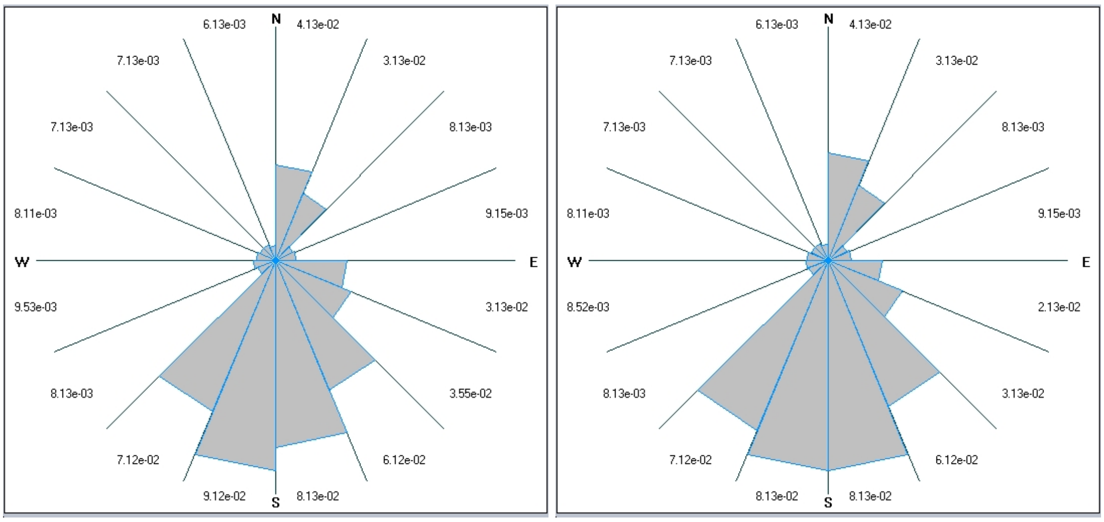
- Meteorological data.
- Population categories and population density.
- Accidents exposure times.
- Mitigation parameters.

Meteo aggregation and meteorological data

With ARIPAR the accident consequence analysis is performed off-line considering different aggregations of Wind velocity - *Pasquill* stability classes. The number and type of aggregations are generally determined at the beginning of the study on the basis of the meteorological conditions during the reference year. In the present case, two aggregations were considered:

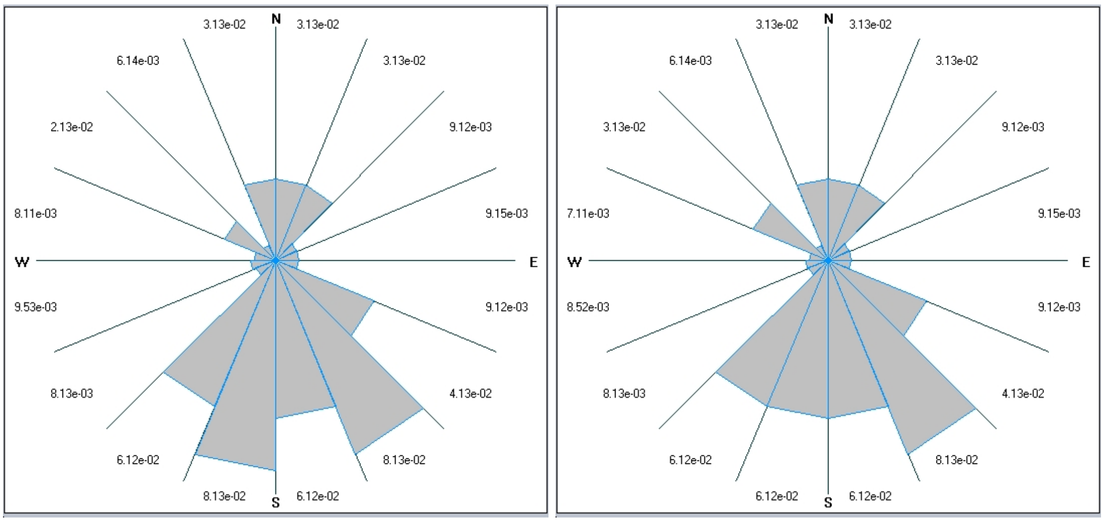
Aggregation	*Pasquill* stability class	Wind speed
1	C	3.6
2	F+G	2.3

The area risk was calculated considering a wind rose, for each different time period (Summer-Spring and Winter-Autumn), expressing the wind direction and corresponding probability. The data employed for the present case are depicted in Figure 48 and Figure 49.



a) *b)*

Figure 48: Summer-Spring, a) Pasquil C – WS 3.6, b) Pasquil F+G – WS 2.3



a) *b)*

Figure 49: Autumn-Winter, a) Pasquil C – WS 3.6, b) Pasquil F+G – WS 2.3

The wind is supposed to blow towards the centre of the wind rose and its probability is given for 16 sectors (22.5 degree wide).

<u>Population Categories and population presence</u>

The determination of the social risk requires the distribution of the population in the impact area. In addition ARIPAR allows classifying the population into different classes depending on their exposure frequency expressed in term of time presence in the given point. Example of population classes is residents, workers, etc. Each category is defined by the probability of presence indoor and outdoor during day and night and for each time period. In the present case the following classes/probabilities were considered:

Classes	**Spring - Summer**		**Autumn - Winter**	
	Indoor probability	Outdoor probability	Indoor probability	Outdoor probability
Residents	*0.5*	*0.5*	*0.8*	*0.2*
Workers	*0.5*	*0.5*	*0.5*	*0.5*
People involved in leisure activities (sport)	*0.1*	*0.9*	*0.7*	*0.3*

The population can be seen as uniformly distributed into small zones (polygons) covering the residential, industrial, commercial areas. Each zone is surrounded by the sides a polygon. Few attributes are then associated with the polygon, e.g. name, type, population density. In the case of the present benchmark the population distribution is illustrated in Figure 50.

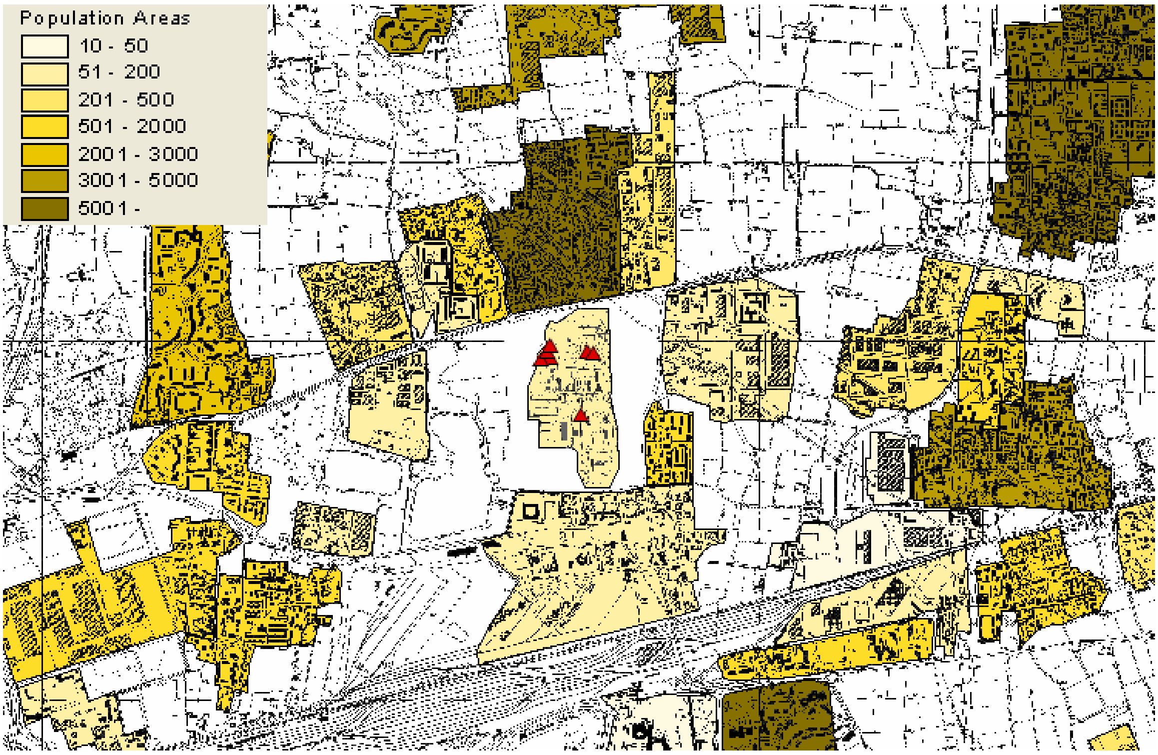


Figure 50: Population distribution around the reference plant (the legend indicated the number of people distributed in areas with the specified colour)

Description of the point risk sources

Each accidental Scenario postulated in the hazard identification analysis is associated to a risk source from which it can originate. The risk sources of the BEQUAR exercise are depicted in Figure 51.

For each risk source the following data set was uploaded on the ARIPAR database:

- Frequency of the initiating and top events.
- Consequence analysis results.
- Exposure times which are necessary to calculate the doses.
- A mitigation factor which is a multiplicative factor accounting of the possible protection measures of the individuals against the accident effects (e.g. being indoor or outdoor). The value 1 of this parameter means no protection, whereas the value 0 means total protection.

For all the BEQUAR Scenarios a mitigation factor equal to 0.5 was used.

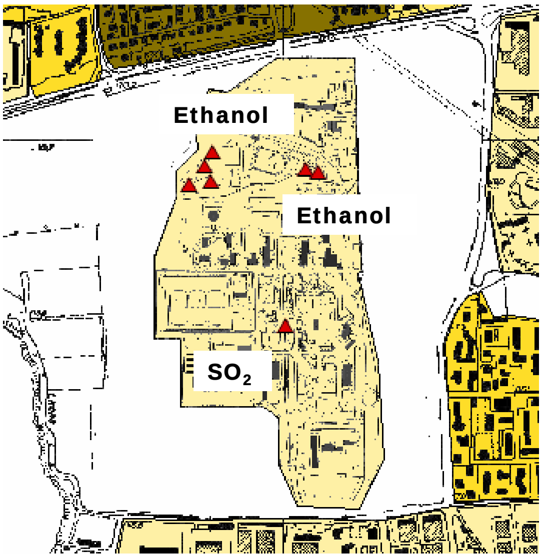


Figure 51: Risk sources (red triangles) from the potential accidents could originate

2.3 Risk calculation for selected sources

The determination of the area risk is performed for a selected subset of risk sources. This procedure sums up the risk contributions of the Scenarios of the selected sources in each point of the calculation grid. The present section describes the results of the area risk analysis conducted by: (*i*) aggregating the risks of all sources and (*ii)* considering the contribution of each single accident Scenario on the final risk. The calculation was conducted by considering all accident Scenarios described in the previous sections, the accident frequency data listed on Table 6 on page 38, the consequence damage curves as calculated by using PHAST 6.42 (DNV Technica, Norway), and the vulnerability models marked in bold of Table 17 on page 59.

Local Risk

The contribution to local risk by all risk sources is depicted in Figure 52. This shows that the risk is mainly concentrated within the reference plant and, to some extent, in the northern direction. The major contribution to risk is given by the presence of the tank wagon containing sulphur dioxide. This can be established by comparing the local risk figure obtained by considering separately the contribution by the tank wagon and the ethanol tanks (Figure 53).

The contribution to the overall risk by the different accident Scenarios, which are associated to the tank wagon risk source, is shown in Figure 54. From this comparison, it is evident the major role played by Scenarios K111 and K121. The first refers to the catastrophic rupture of the tank which account for the spread of risk in a highly populated area, whist the second that is associated to the flange failure, is responsible for higher values of risk concentrated within the plant but with negligible off-site effects. All the other Scenarios provide negligible contribution to the overall risk both on site and off site.

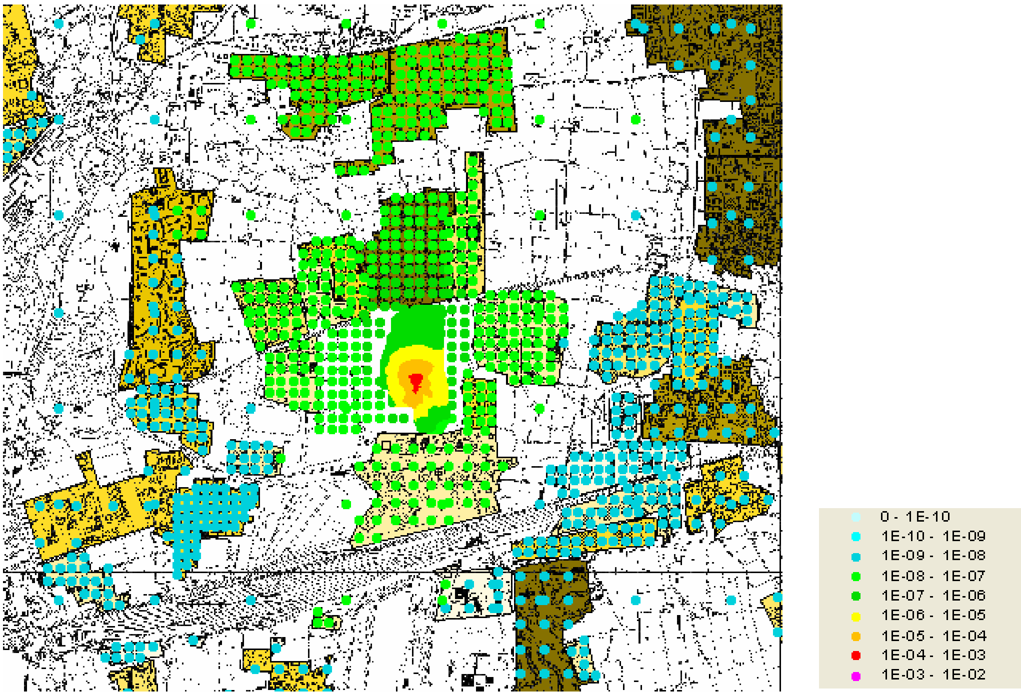
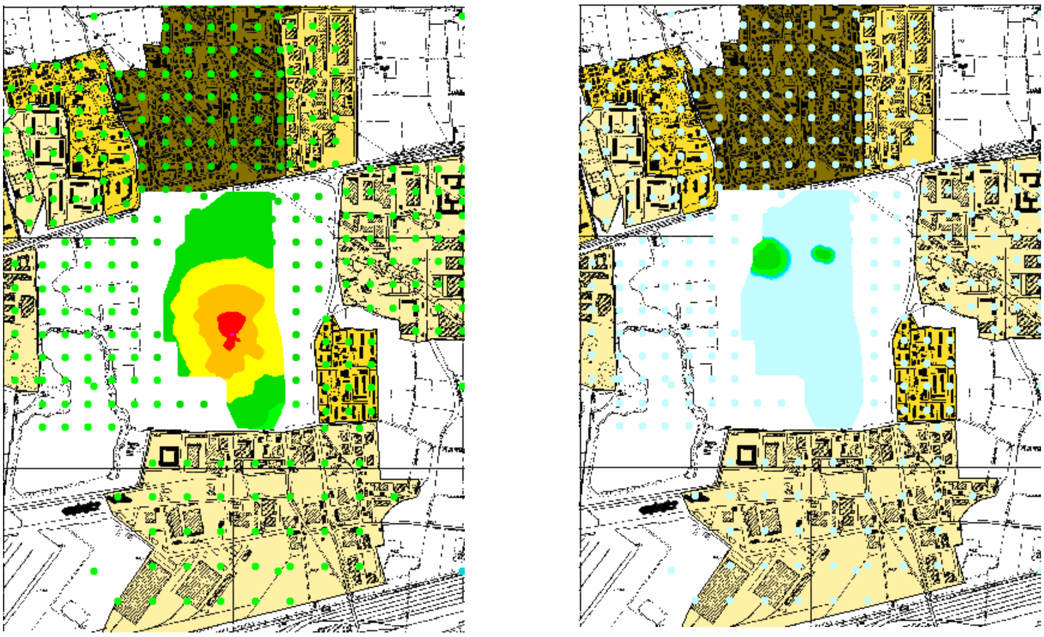
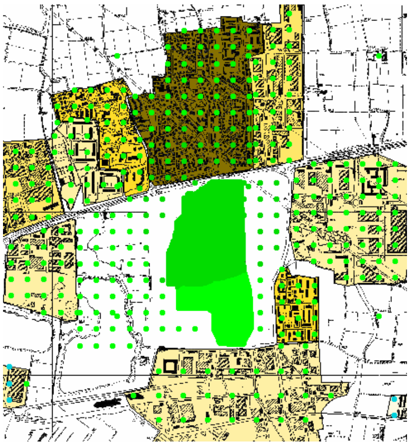


Figure 52: Local risk of the BEQUAR plant: contribution by all risk sources

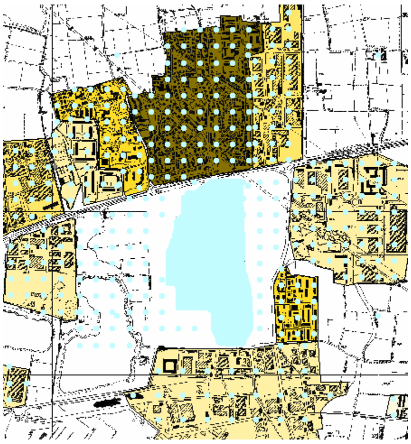


A) *B)*

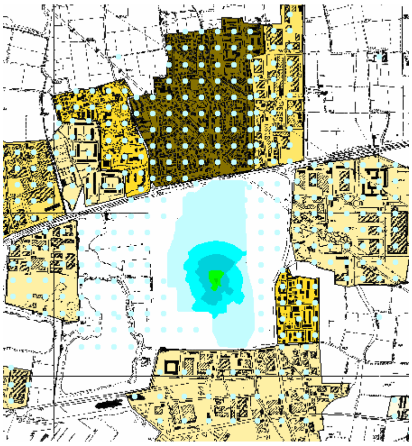
Figure 53: Contribution to risk by: A) Tank Wagon and B) Ethanol Tanks



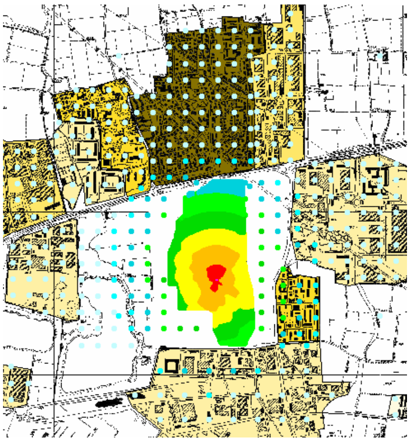
K111



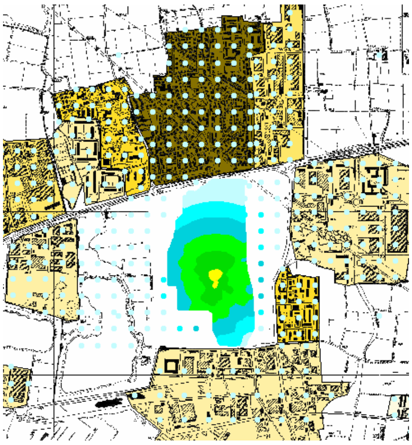
K211



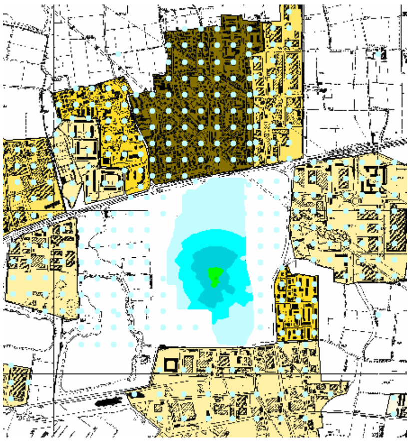
K221



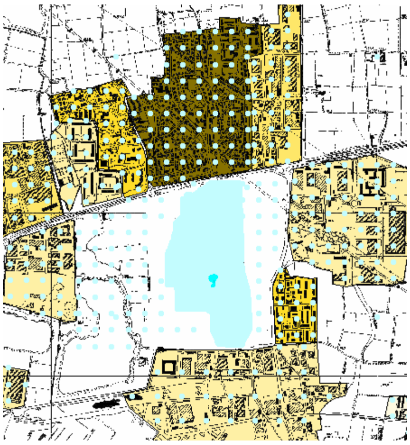
K121: Isolable flange failure



K151: Not Isolable flange failure



K131: Isolable flex. pipe failure



K161: Not Isolable flex. pipe failure

Figure 54: Contribution to local risk by the different Scenarios

Societal risk

As previously described the societal risk is represented by ARIPAR through the *F-N curve* which is a graph of the inverse cumulative frequency of accidents capable of causing the reference damage to a number of people greater than or equal to N.

The FN curve calculated by considering the population distribution previously described is reported in Figure 55 whilst the contribution to the societal risk by the different accident Scenarios is shown in Figure 56. The figure shows the contribution of the five first Scenarios, which provide a contribution to risk. The effect of the other Scenarios was negligible and, therefore, it was not reported.

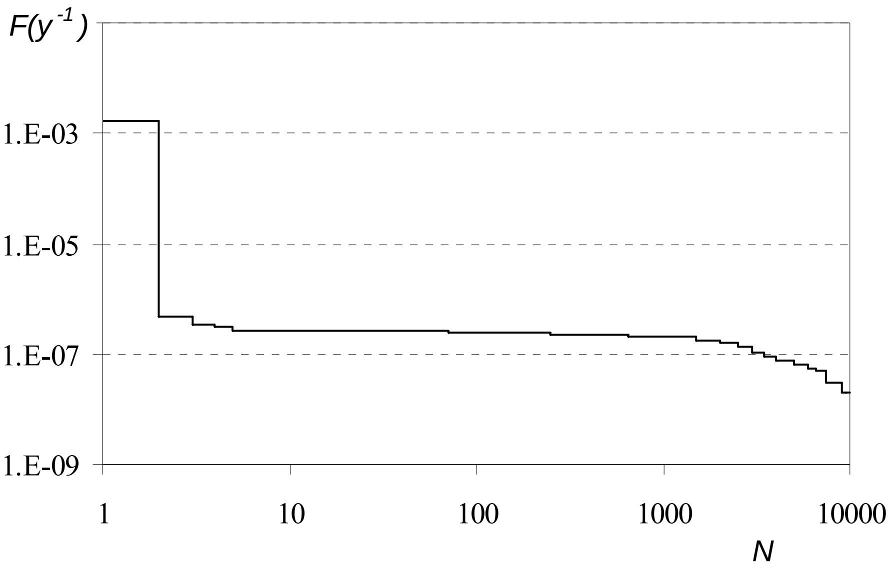


Figure 55: FN curve for BEQUAR reference plant

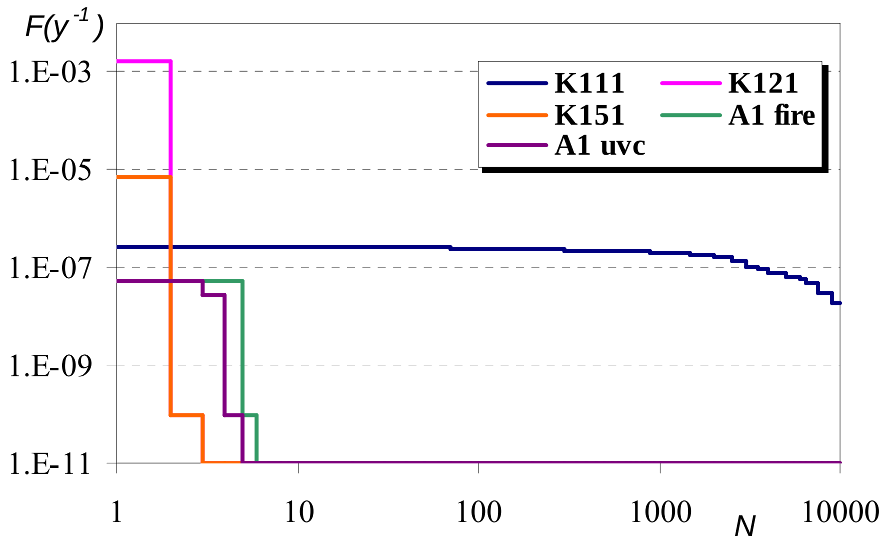


Figure 56: Contribution to societal risk by the different accident Scenarios

From Figure 56 it is evident that, under the assumptions of the present study, the only accident Scenario contributing to off-site risk is the catastrophic rupture of the sulphur dioxide wagon tank due to collision with other railway tank wagon (K111), which has some potential (even if quite unlikely) of producing harm to a number of people greater of 10. All the other Scenarios are more associated to occupational safety related issues as their effect is mainly confined within the plant.

ARIPAR provides also a ranking of the different accident Scenarios in term of their contribution to the overall risk. The result of this calculation is given in the table below:

Scenario	Description	% to the overall risk
K111	Tank wagon catastrophic rupture due to collision with other railway tank wagon	62.23
K121	Isolable flange leakage: ø10 mm horizontal outflow during 20 minutes (isolable)	37.57
K151	Not Isolable flange leakage: ø10 mm horizontal outflow (20 min) & vertical outflow from ø40 mm (10 min)	0.16
K211	Tank wagon catastrophic rupture due to collision during tank wagon change	0.02
A11 pool fire	Catastrophic rupture of A1 tank: delayed fire	0.006
A11 uvc	Catastrophic rupture of A1 tank: delayed uvc explosion	0.003

Table 20: Risk ranking for the different accident Scenarios

3. RISK ANALYSIS REVIEW

3.1 General

The focus of the preset session is on the impact of the different reviews conducted by the BEQUAR members on the overall risk analysis of the reference establishment. For each BEQUAR member, different risk maps and FN curves were produced and compared. These were calculated by using their reviewed data as input data for ARIPAR. Specifically, as it was shown in the previous chapters, it consisted of the frequencies of the accident Scenarios, the release times and the vulnerability models used to conduct the risk analysis.

The preliminary comparison of the risks, as produced by using the review data of the different BEQUAR members, was conducted during a project meeting (M3, 30-31 January 2006, Ispra). The purpose of the meeting was also to simulate the discussion between the ‘fictitious’ operator of the reference plant (JRC) and the safety authority ‘inspector’ (BEQUAR members). The ‘inspector’ was supposed to communicate his/her remarks to the operator concerning the proper position on the reference risk analysis. It was therefore also the occasion in which the BEQUAR members had the possibility to reconsider their positions is relation to certain data that they suggested to modify in their review. The BEQUAR members where then asked to introduce the new set of the reviewed data directly into ARIPAR and to run their area risk analysis exercise.

The results of the calculations obtained by using ARIPAR are reported from Figure 57 to Figure 74, which represent the impact on risk analysis of the reviewing action on the input data, for each member of BEQUAR.

From a first comparison, the difference amongst BEQUAR members is quite evident both in terms of:

- the absolute figure of risk (the overall risk is much higher for some members than others)
- the relevance of the different Scenarios in contributing to the overall risk .

In general, the majority of the BEQUAR members assessed a higher risk if compared to the reference estimate (see Figure 52 and Figure 55), which denotes their more conservative approach.

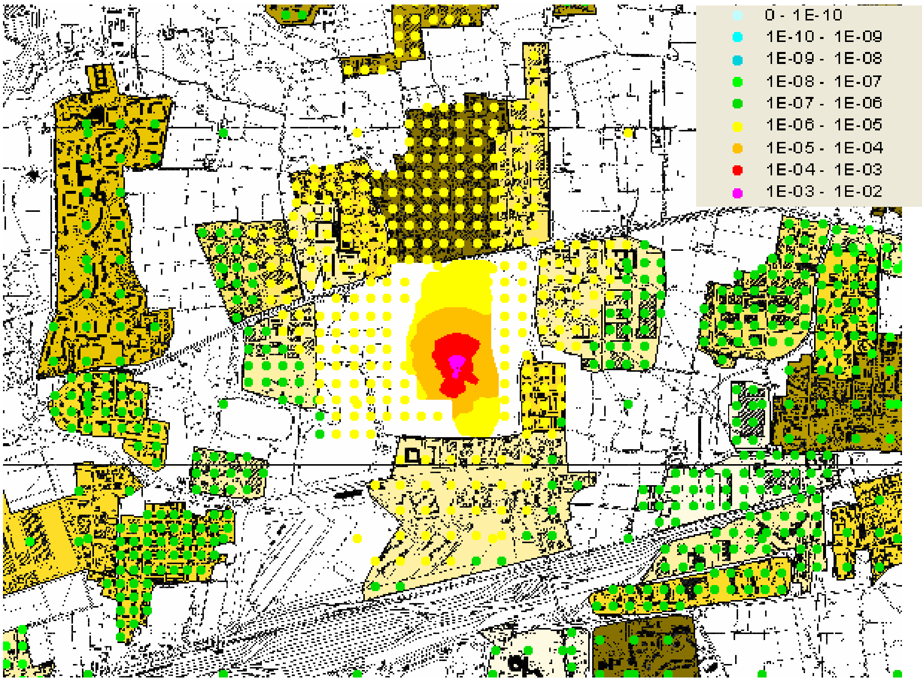


Figure 57: Local Risk calculated by using BEQUAR Member N. 3's input data

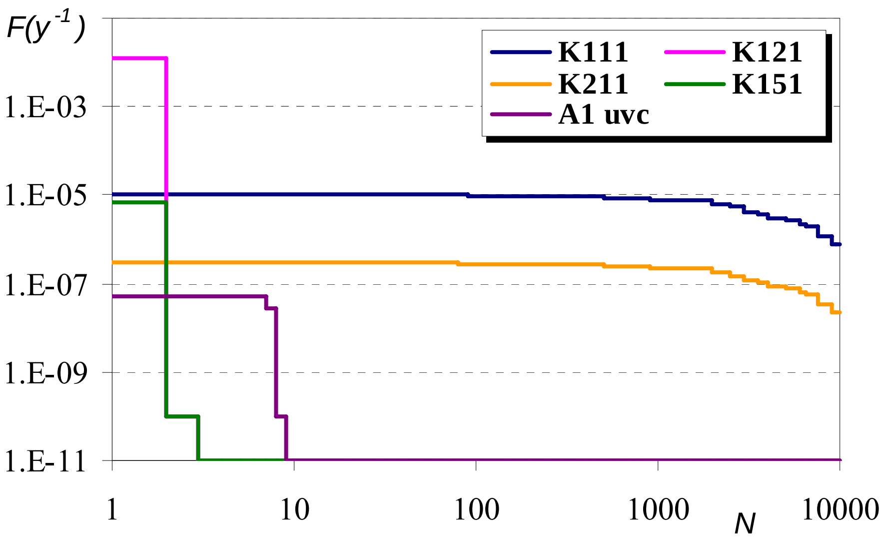


Figure 58: Societal Risk calculated by using BEQUAR Member N. 3's input data

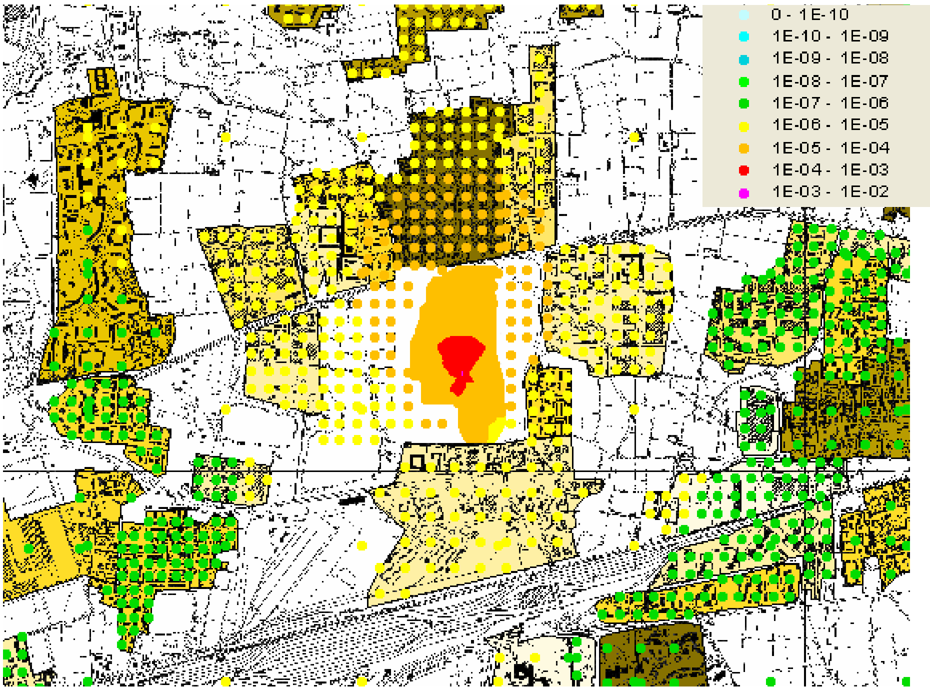


Figure 59 :Local Risk calculated by using BEQUAR Member N. 4's input data

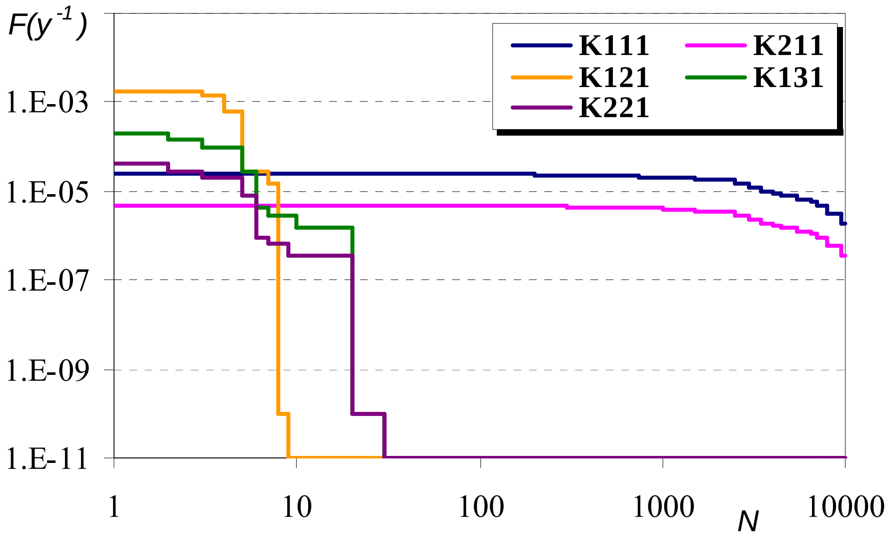


Figure 60: Societal Risk calculated by using BEQUAR Member N.4's input data

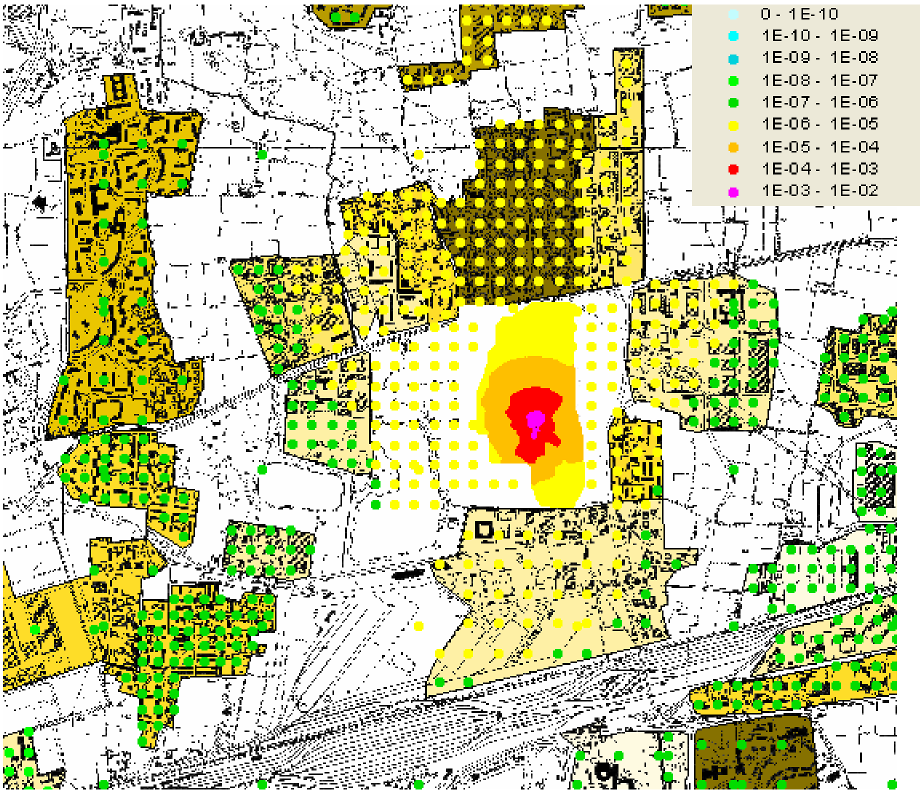


Figure 61: Local Risk calculated by using BEQUAR Member N. 5's input data

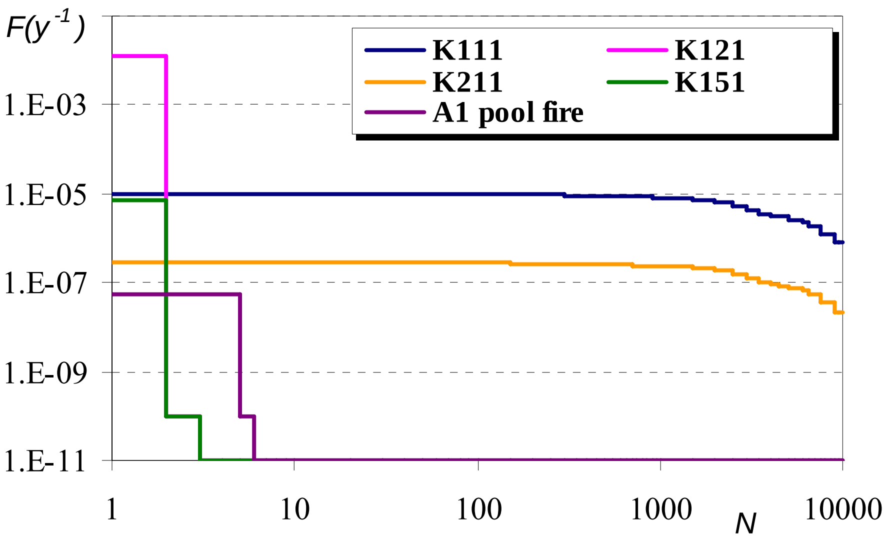


Figure 62: Societal Risk calculated by using BEQUAR Member N.5's input data

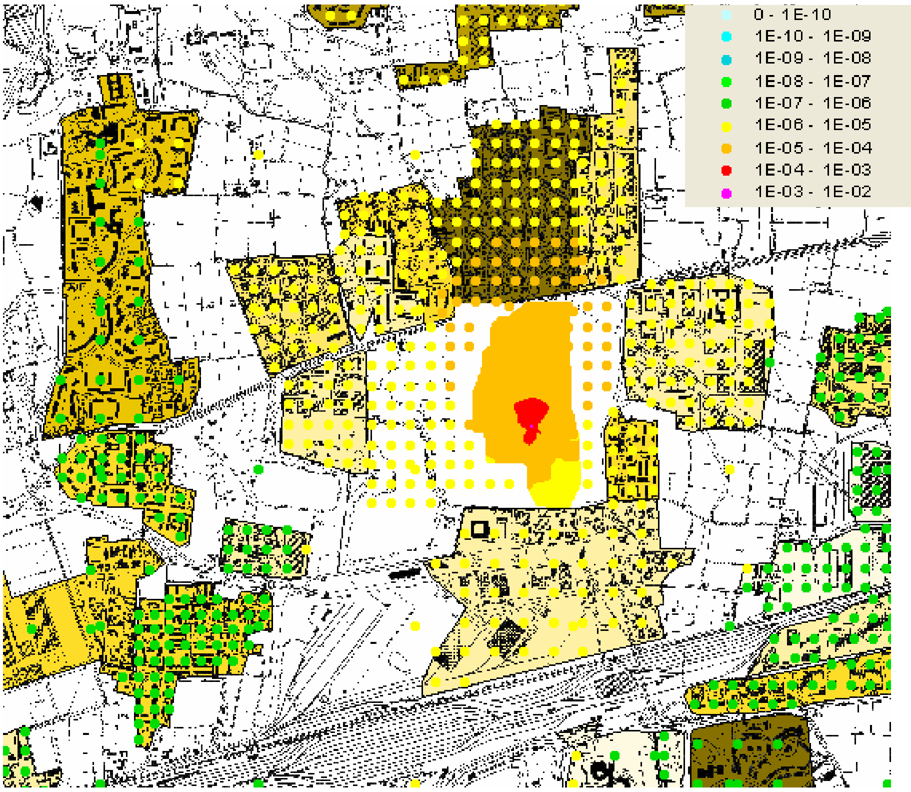


Figure 63: Local Risk calculated by using BEQUAR Member N. 6's input data

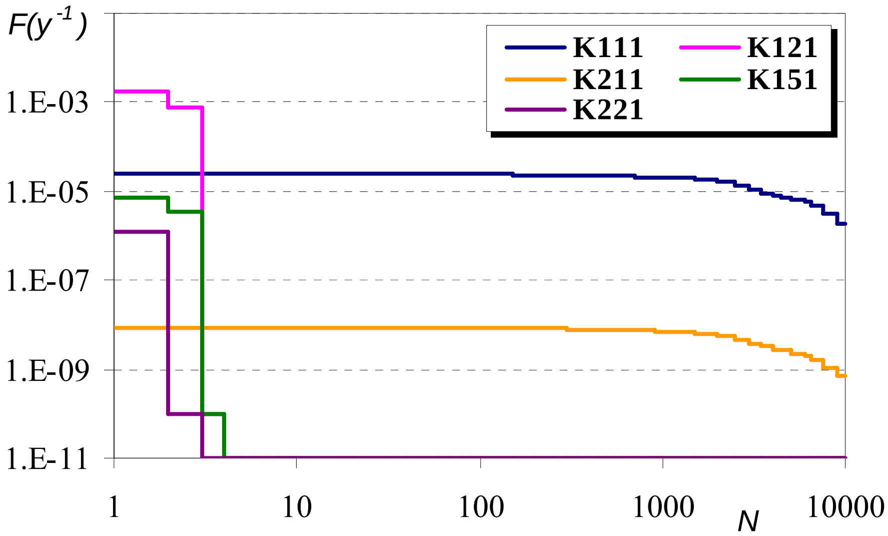


Figure 64: Societal Risk calculated by using BEQUAR Member N.6's input data

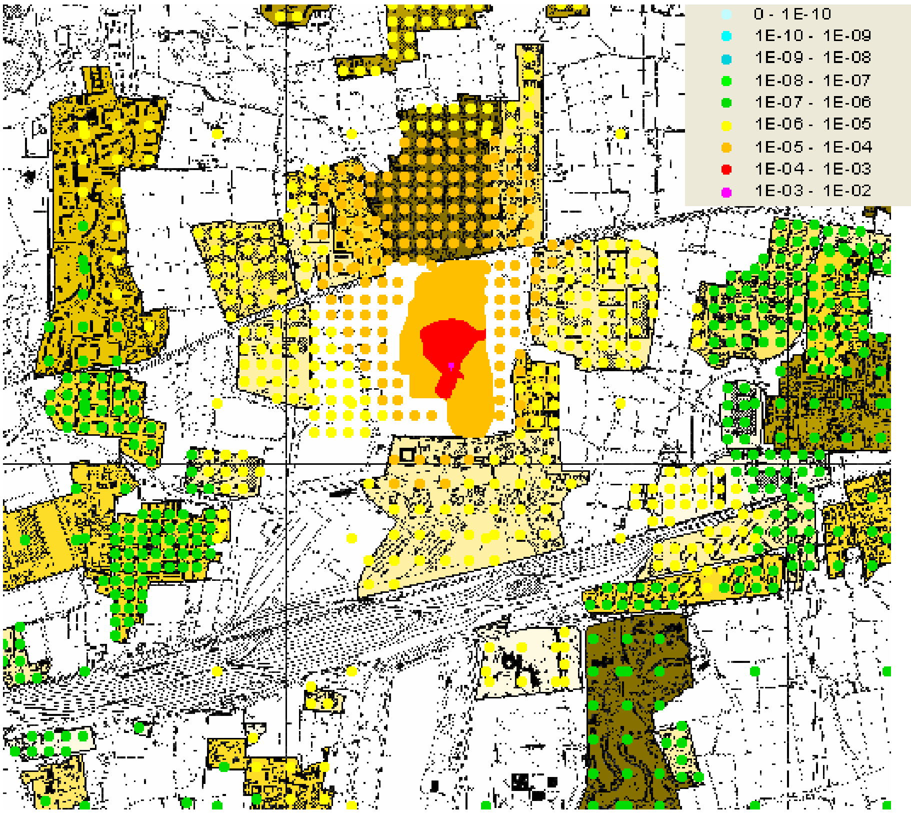


Figure 65: Local Risk calculated by using BEQUAR Member N. 7's input data

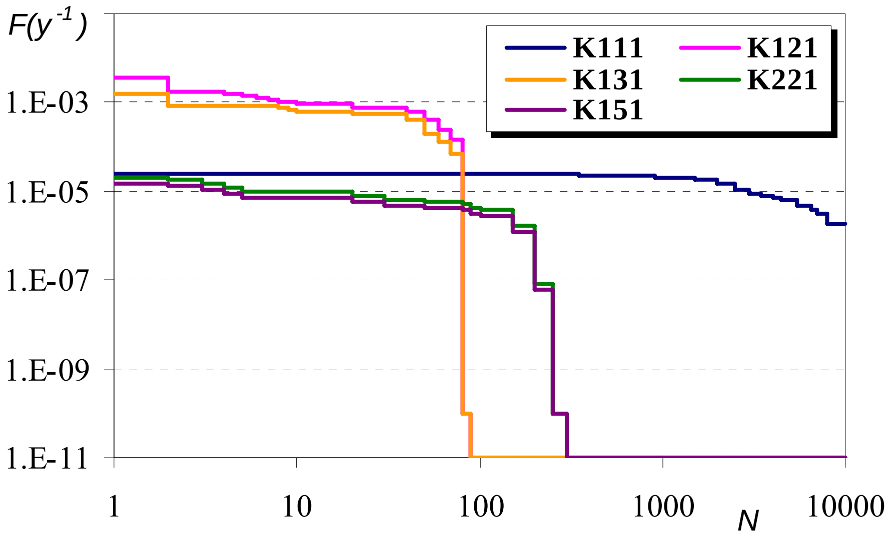


Figure 66: Societal Risk calculated by using BEQUAR Member N.7's input data

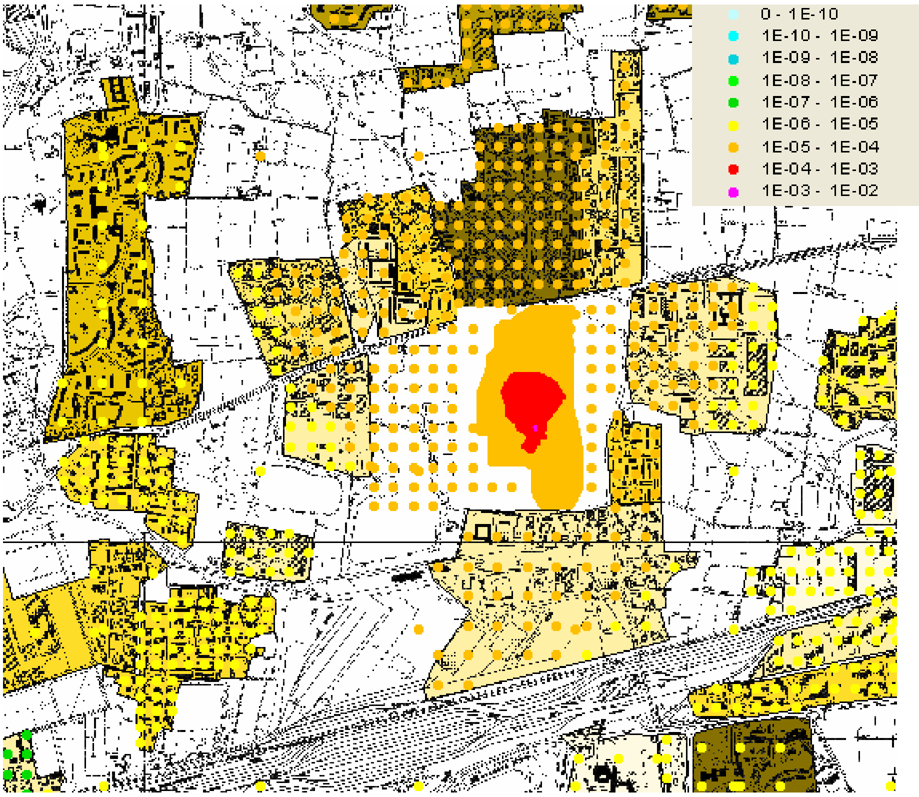


Figure 67: Local Risk calculated by using BEQUAR Member N. 9's input data

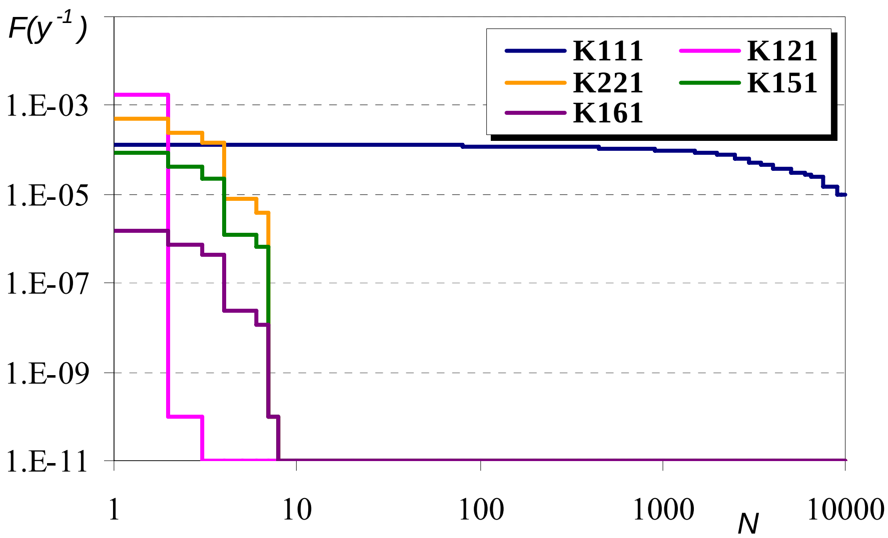


Figure 68: Societal Risk calculated by using BEQUAR Member N.9's input data

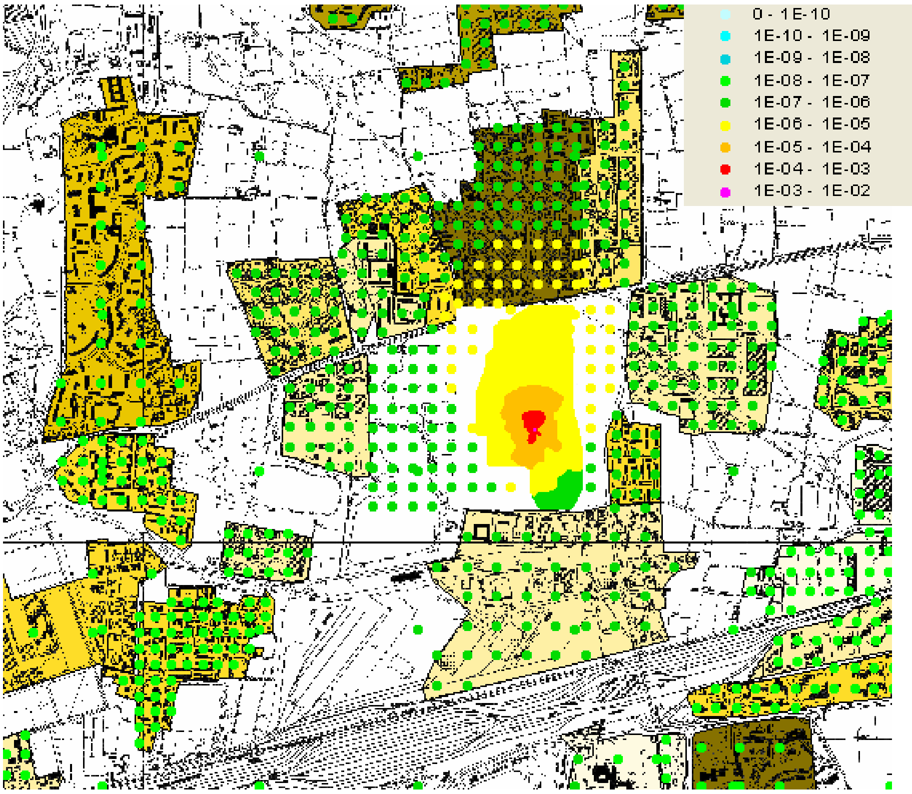


Figure 69: Local Risk calculated by using BEQUAR Member N 10's input data

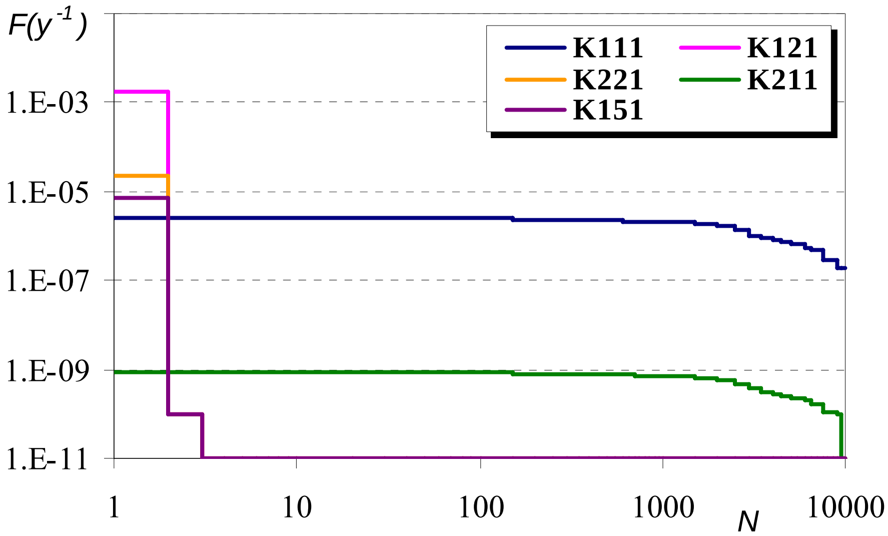


Figure 70: Societal Risk calculated by using BEQUAR Member N.10's input data

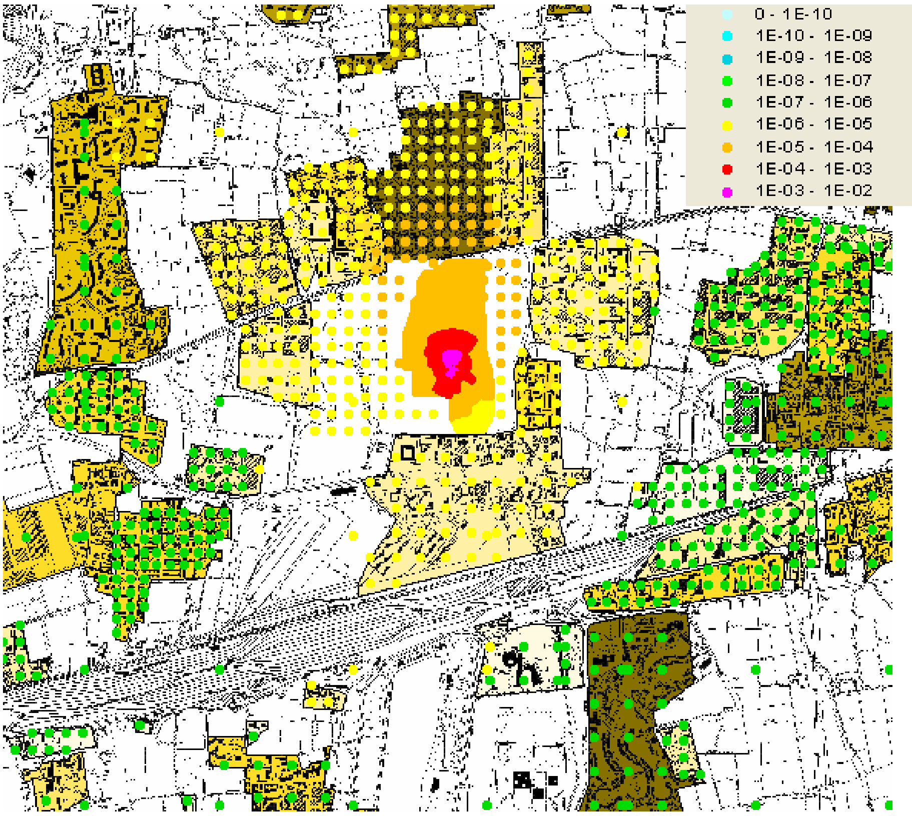


Figure 71: Local Risk calculated by using BEQUAR Member N 11's input data

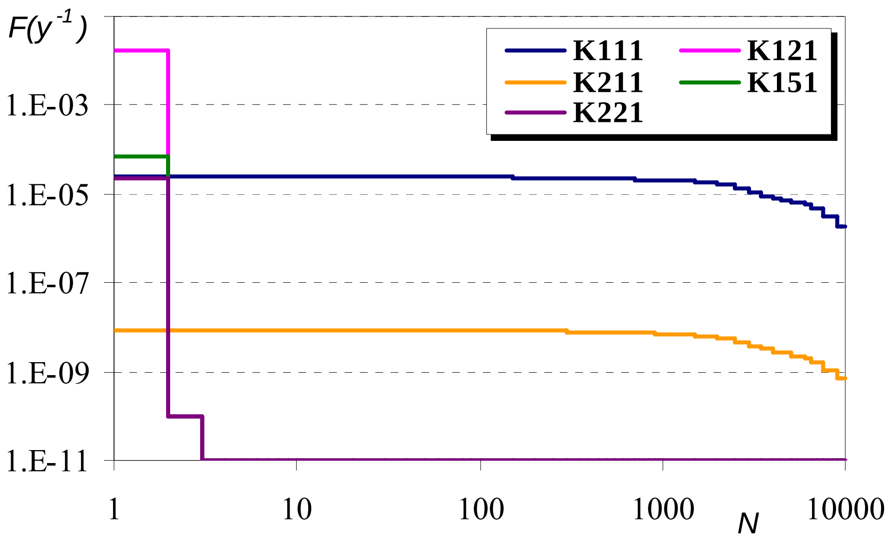


Figure 72: Societal Risk calculated by using BEQUAR Member N.11's input data

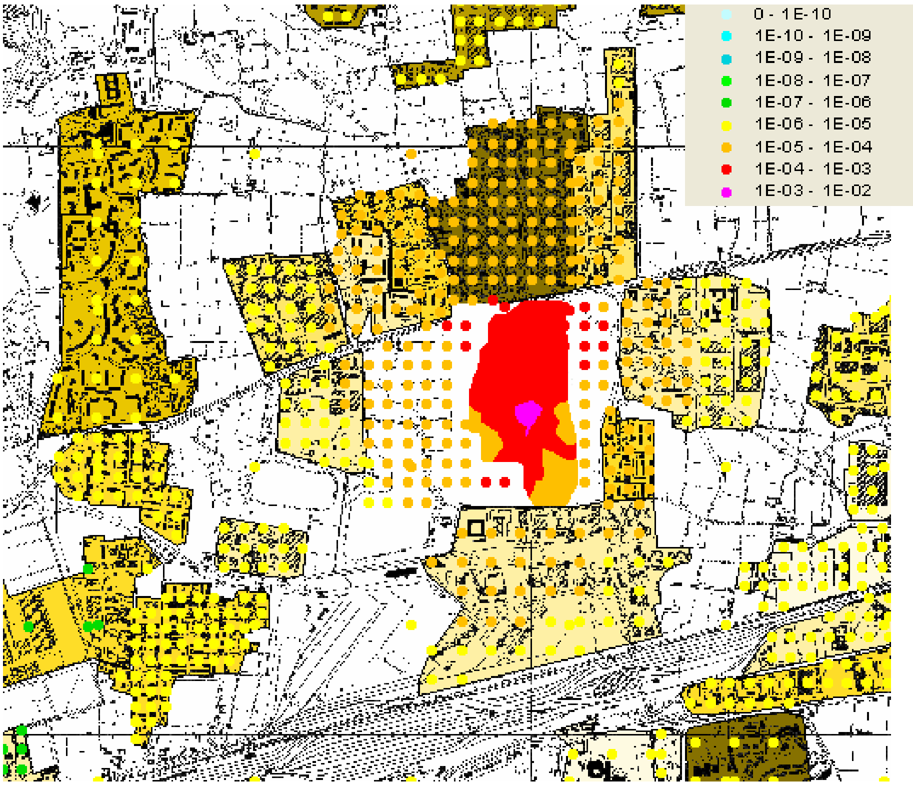


Figure 73: Local Risk calculated by using BEQUAR Member N 12's input data

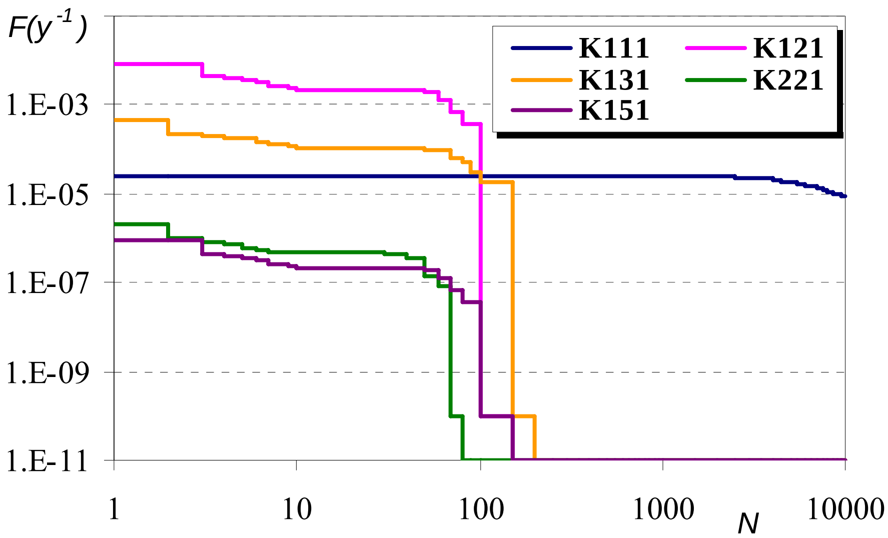


Figure 74: Societal Risk calculated by using BEQUAR Member N.12's input data

3.2 Scenario by Scenario analysis

The present section summarises the comparison of the FN-curves obtained by using the reviewed data of the BEQUAR members. The analysis was conducted by separately considering the contribution to the overall risk by each single accident Scenario.

Scenario K111

54 t SO_2 release to the environment as a consequence of the catastrophic rupture of the SO_2 tank wagon due to mechanical impact with hydrochloric acid or alkali tank wagon.

The comparison of the calculations for the different BEQUAR members for the K111 Scenario is shown in Figure 75. All the FN-curves calculated by using the reviewed data of the BEQUAR members are clearly above the reference curve (red), which indicates their estimation for higher risk if compared to the reference analysis. The off-site potential of this Scenario was confirmed and it was considered as the 'worst case' Scenario by all the BEQUAR participants.

As the members estimated higher values for the occurrence frequency of this Scenario (ca. 2 order of magnitude on average), their F-N curves were vertically translated from the reference toward the higher frequency direction. For member n. 12 (cyan) it can be noticed also a distortion of the curve for high values of N. This is due to the fact that, amongst the different members who completed their analysis and therefore appearing in the figure, member n. 12 was the only having chosen the more conservative probit model, which differs significantly from other selected models.

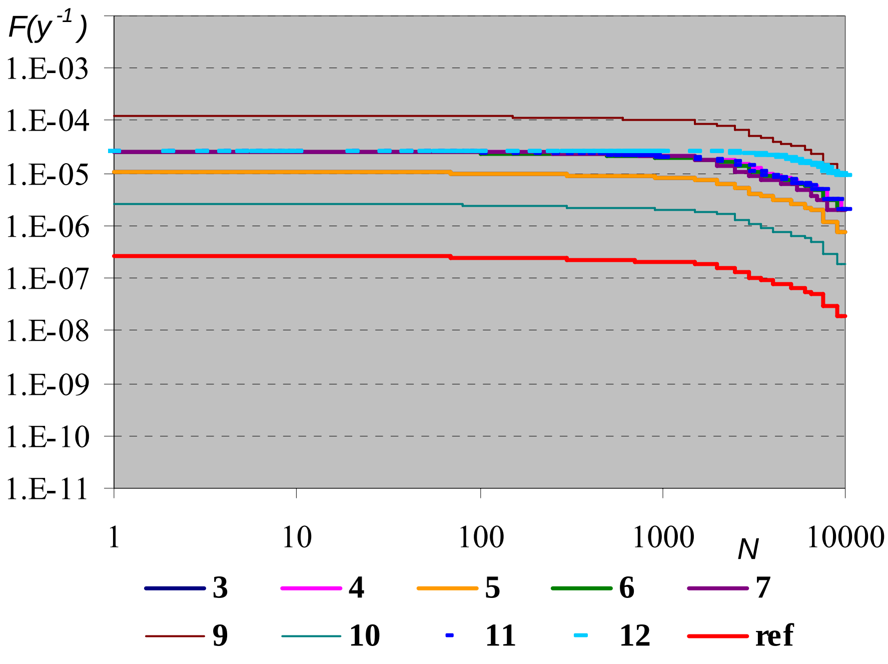


Figure 75: F-N curve for K111 Scenario: the different curves refer to the different BEQUAR members and are compared to the curve (red) of the reference risk analysis

Scenario K121

Isolable leakage of equivalent ø10 mm due to failure of the flange

The potential effects of Scenario K121 as assessed by the reference analysis are limited to a small area centrally located and embedded within the reference plant (on-site effects). However the relatively high estimated frequency makes it risk significant.

The spread of responses by the BEQUAR members is quite relevant as shown in Figure 76 although some members provided same outcome (i.e. 9 and 10 were equivalent to the reference, whilst 3 was equivalent to 5). The members who showed a more conservative approach are member n. 7 and member n. 12. Also in these cases, the major role was played by the selected models for assessing the vulnerability to sulphur oxide. As previously indicated, member 12 selected the most conservative probit model, whilst member 7 selected threshold limits which, in the present case, resulted in a more conservative approach for lower values of toxic concentration (i.e., in the range 1-300 mg/m^3) if compared to the reference case. As for this Scenario lower concentration values play an important role, this is the reason why a similar behaviour for member 7 was not noticed in K111.

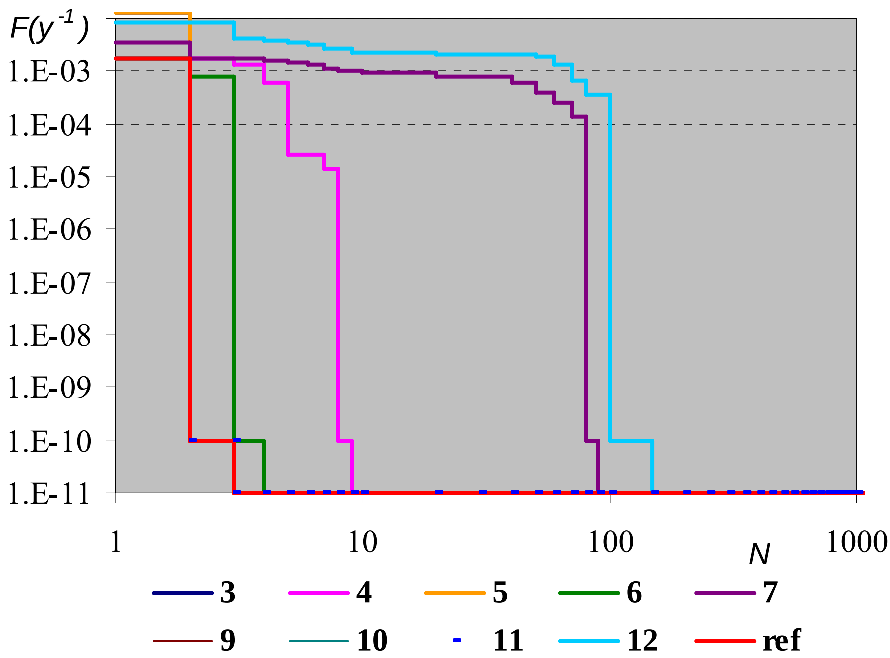


Figure 76: F-N curve for K121 Scenario: the different curves refer to the different BEQUAR members and are compared to the curve (red) of the reference risk analysis. The curves of members 9 and 10 do not appear because they superimpose with the reference. The curve of member 3 is underneath the curve of member 5

The peculiarity of this Scenario in term of the uncertainty of its potential for producing off-site risks, has suggested further investigation. In particular, during one of the project meetings, it was decided to make a thorough analysis on the effect of the assumption made i.e. the reaction time of the operators in case of release from the flange. The plant operator provided a reaction time of 20 minutes in case of proper functioning of the sensor system and 30 minutes otherwise. This values account of the time necessary by the intervention operator to detect the release, to wear the proper protection equipment and to stop the release by closing the tank wagon valve, which is located on the top of the tank.

The simulation was conducted by assuming longer reaction times (40, 60, 120 minutes), which refer to a situation in which the operator of the plant is unable to intervene due to unexpected conditions. In such a case external intervention could be required. The results of the calculation are show in Figure 77 that shows a much more critical situation, which if combined also to a different choice of the vulnerability mode it would lead to a risk picture with significant off-site potential.

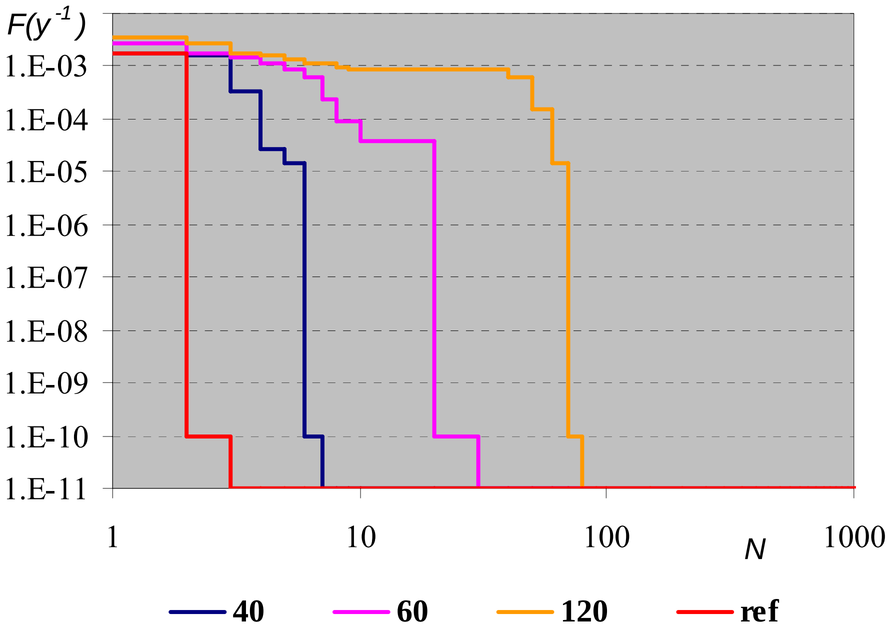


Figure 77: K121 Scenario; FN-curve - Simulation for different values of the response time: 40, 60, and 120 minutes

Although, the feedback of the members on the reaction and repair times reported in a previous session did not lead to significant differences with respect the reference analysis (see page 60) it should be emphasised the fact that response time depends very much on the specific procedures and the training activities put in place at the plant. As these aspects were not specifically explored by the BEQUAR members during their visit at the plant, it was commonly recognised that further detailed analysis is necessary.

Scenario K211

54 t SO_2 release to the environment as a consequence of the catastrophic rupture of the SO_2 tank wagon due to mechanical impact during wagon change

The comparison for K211 is particularly interesting because the reference analysis classified this Scenario as quite risk insignificant, due to the very low value of estimated frequency (10^{-10} y^{-1}). By contrast, the response of the BEQUAR member was quite different (see Figure 78). Four members (n. 4, 5, 6 and 11) presented FN-curves with the typical shape of catastrophic failure Scenarios. Their reviewed frequency of occurrence was much higher (10^{-8} - 10^{-4} y^{-1}) than the reference value, which explain for this behaviour. Members 7 and 12, who selected lower values of frequency, provided higher values of risk only for lower values of N (300 and 100, respectively).

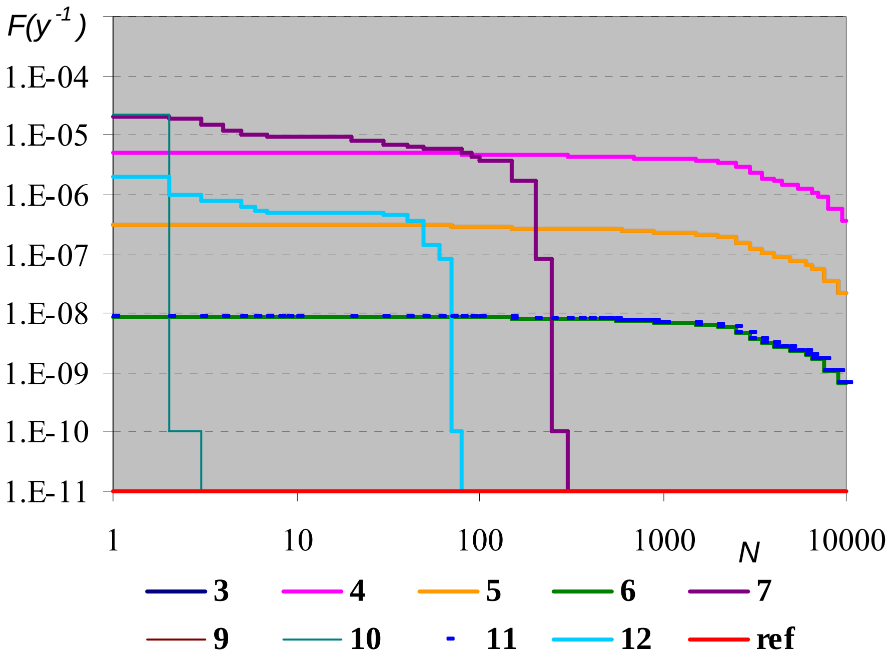


Figure 78: F-N curve for K211 Scenario: the different curves refer to the different BEQUAR members and are compared to the curve (red) of the reference risk analysis. The curve of members 3 does not appear because it is underneath the curve of member 5. The curve of member 9 is underneath the reference (negligible)

Scenario K221

Not Isolable leakage of due to failure of flange connection AND failure of tank wagon valve; vertical outflow from ø40 mm during 10 minutes (time required for mounting the shut-off valve)

The reference analysis ranked this Scenario as risk insignificant. This was due to the combination of a quite low estimated frequency (10^{-6} y^{-1}) and the limited amount of substance release. Nevertheless, the FN-curves obtained by the BEQUAR members (Figure 79) tend to depict a different situation. Although the estimated risk is mainly associated to on-site situations (i.e. risk completely negligible for N>100), a number of BEQUAR members (n. 4, 7 and 12) identified a risk picture of a certain relevance. For members n. 12 the same considerations expressed for the previous Scenarios (vulnerability models) can be made, whilst for members n. 4 and 9 it should be noticed that both the reviewed frequency and the response/repair times were higher if compared to the reference.

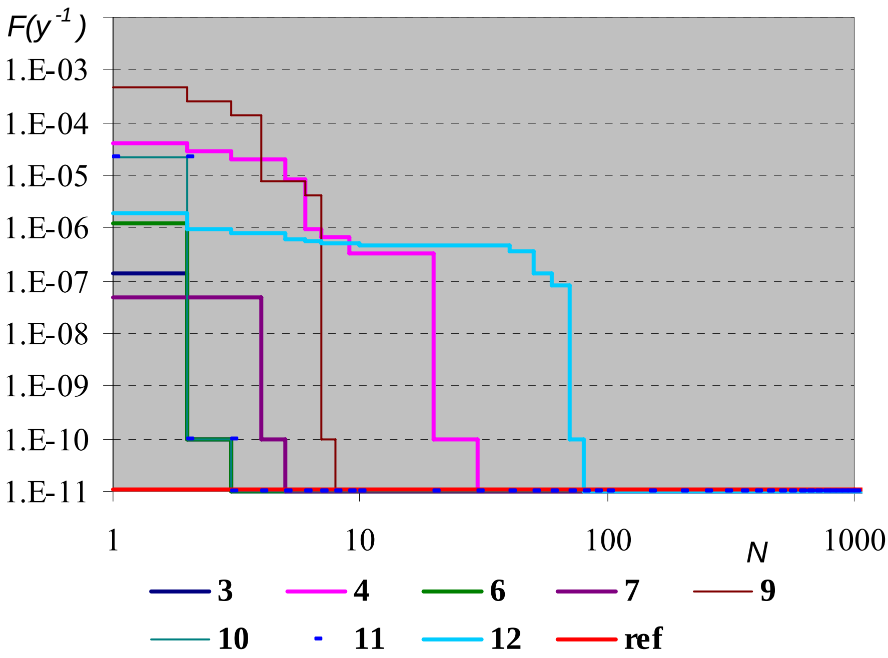


Figure 79: F-N curve for K221 Scenario: the different curves refer to the different BEQUAR members and are compared to the curve (red) of the reference risk analysis

Scenario K131

Isolable leakage due to flexible pipe rupture AND failure of the protection valve (spring valve)

The reference analysis ranked this Scenario as risk insignificant. This was due to the combination of a quite low estimated frequency (5 10^{-7} y^{-1}) and the limited amount of substance release. By contrast, the review of some BEQUAR members conducted to a different risk picture (Figure 80). Also in this case members n. 7 and 12 provided higher figures for the risk associated to this Scenario due to their higher reviewed frequency and the more conservative vulnerability models, which were used. Member n. 4 provided a much higher value for the reviewed frequency (5 10^{-4} y^{-1}).

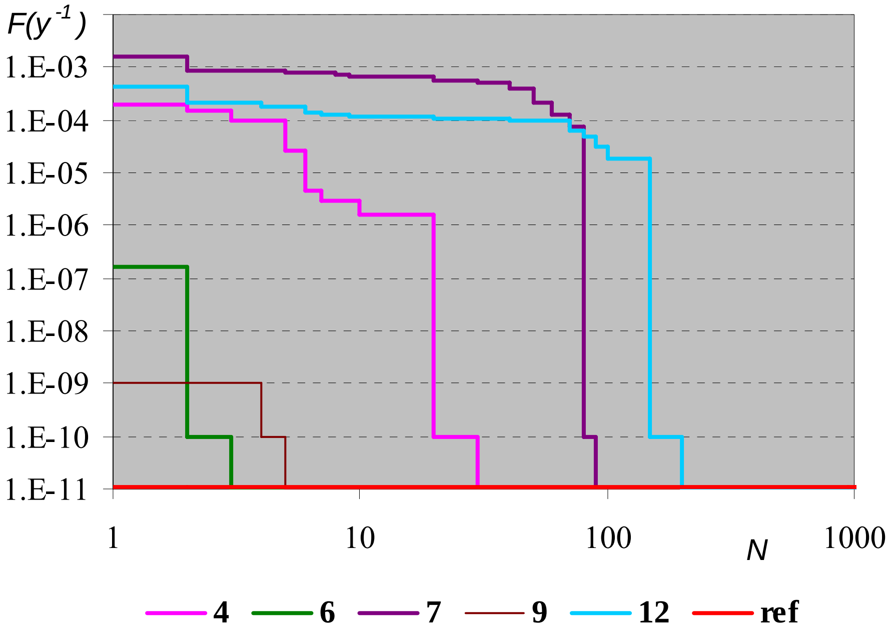


Figure 80: F-N curve for K131 Scenario: the different curves refer to the different BEQUAR members and are compared to the curve (red) of the reference risk analysis

Scenario K151

Not Isolable leakage of equivalent ø10 mm due to failure of the flange AND the tank wagon valve

For this Scenario the reference analysis produced a quite small risk figure with negligible values for N>2. The response of some BEQUAR members is shown in Figure 81 where it should be noticed the higher risk estimated by members 7, 12 and 4.

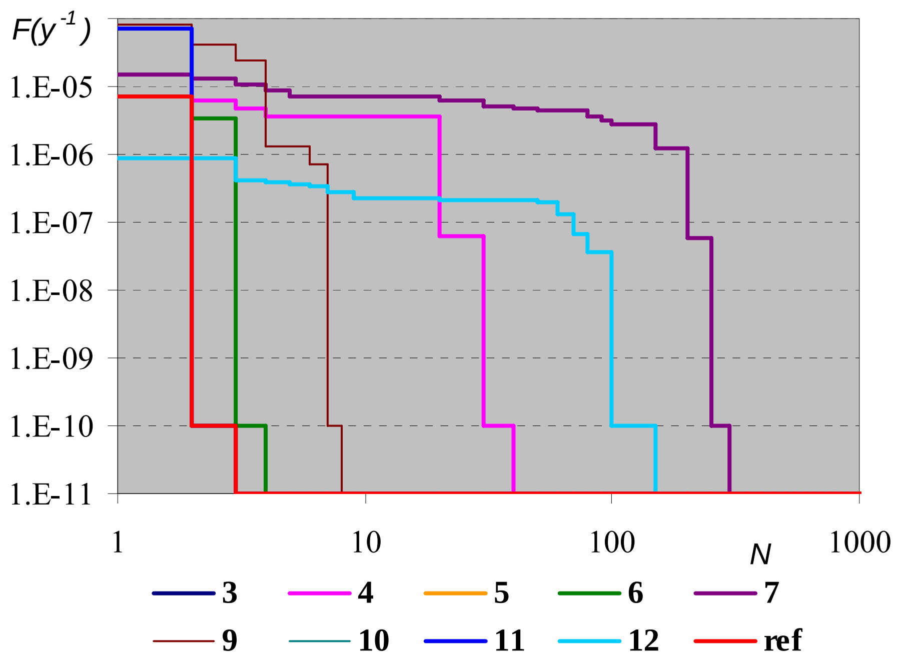


Figure 81: F-N curve for K151 Scenario: the different curves refer to the different BEQUAR members and are compared to the curve (red) of the reference risk analysis. The curves of members 3, 5 and 10 are equivalent with each other and are underneath the reference curve

<u>Scenario K161</u>

Not Isolable leakage due to <u>flexible pipe</u> rupture AND failure of the <u>protection valve</u> (spring valve) AND <u>tank wagon valve</u>

The reference analysis ranked this Scenario as risk insignificant. This was due to the combination of a quite low estimated frequency (2 10^{-9} y^{-1}) and the limited amount of substance release. Also for this case there is a number of BEQUAR members (Figure 82) for which the risk picture is rather different.

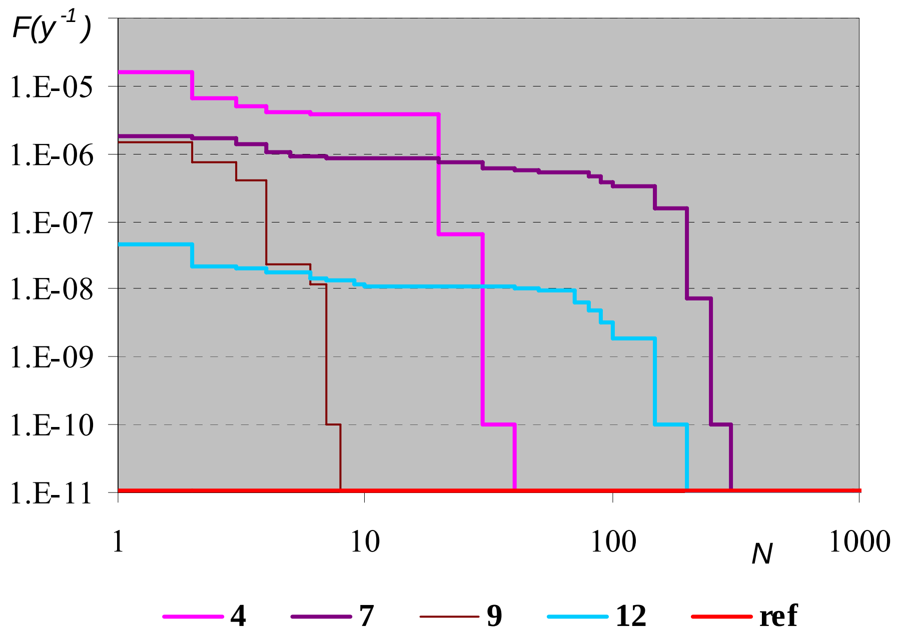


Figure 82: F-N curve for K161 Scenario: the different curves refer to the different BEQUAR members and are compared to the curve (red) of the reference risk analysis

Ethanol related Scenarios

All the Scenarios associated to the release from the ethanol tanks where very risk insignificant. This is also due to the presence of the bund, which prevents the large spread of the release after the postulated catastrophic rupture of the tanks or the failure from the connecting pipe. For all tanks the estimated risk for a potential pool fire or explosion as estimated by the BEQUAR members was negligible and very often even smaller than the estimated risk by the reference analysis.

As an example the calculation of the FN-curves for the Scenario consisting of a pool fire as resulting from the catastrophic release from the biggest tank (A11) are reported in Figure 83.

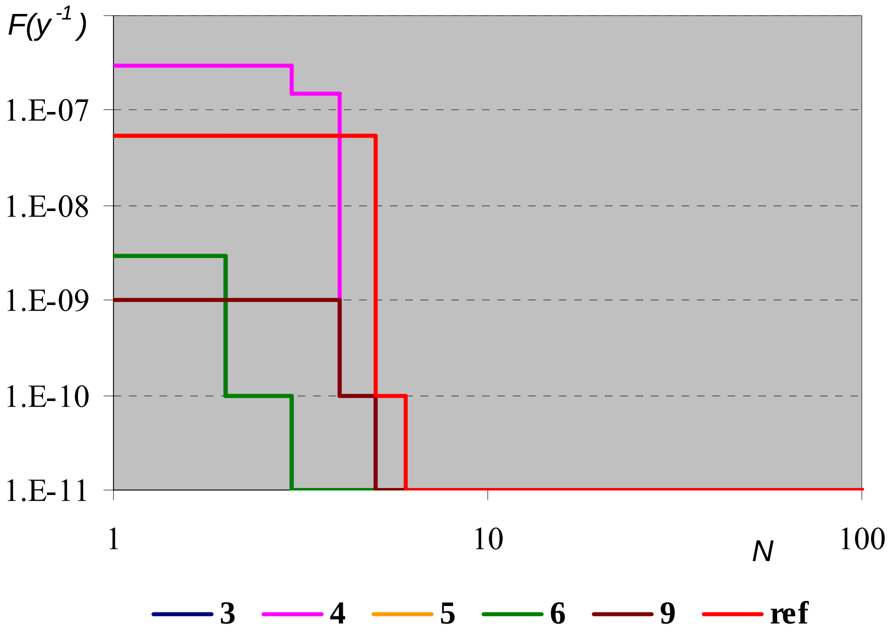


Figure 83: F-N curve for A11 Scenario (pool fire as a consequence of the catastrophic rupture of the A11 ethanol tank: the different curves refer to the different BEQUAR members and are compared to the curve (red) of the reference risk analysis. The curve of member 3 is underneath the curve of member 6, whist the curve of member 5 is underneath the reference curve

3.3 Summary of risk analysis review

From the results presented in the previous sections, it can be established that, in general, the risk estimates obtained by using the reviewed data of the BEQUAR members are normally higher than those presented in the reference risk analysis. The only exception is with the ethanol related Scenarios, for which the estimated risk is very low in both cases.

Such an increase is clearly associated to the general tendency by the BEQUAR members in assigning higher values for the frequency of the postulated Scenarios. Nevertheless it should be noticed that -at least with the exception of the K111 Scenario- the review of the frequency data did not play a major role in quantitative terms. By contrast, the role of the different vulnerability models used for consequence assessment seems to have contributed more to a different outcome of the risk picture.

A point to note is that, in the present analysis, great attention was paid to the influence of frequency data and of the vulnerability models on the final outcome of the risk analysis. For this reason several discussions on the choice of these parameters took place during the BEQUAR meetings. It was however shown that other aspects can play an important role on the overall risk picture. Unfortunately these aspects, which role is not immediately evident in the risk assessment process, are often not considered with the appropriate level of detail. It is the case of certain assumptions such as for instance the reaction time, which did not attract the due attention during the analysis phase but that it demonstrated to be much more risk sensitive then other parameters.

Concerning the relevance of the different Scenarios to the overall risk the comparison of the reference analysis and of the members review is depicted in Figure 84. Scenarios K111 and K121 were considered by far as the most significant by both the reference analysis and the BEQUAR members. However the main difference is for K131, K161 and 211 which are totally negligible in the reference analysis, whilst they were considered as playing a minor role for the BEQUAR members.

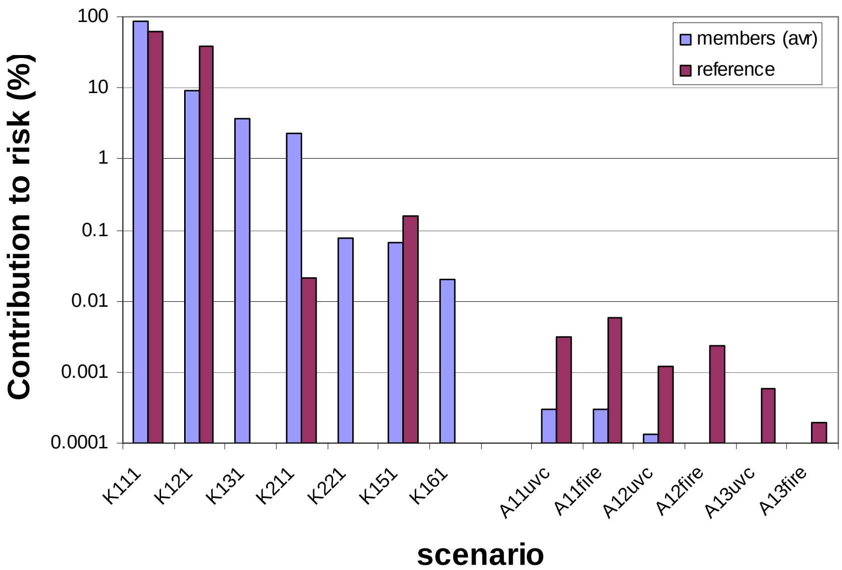


Figure 84: Contribution to the overall risk by the different scenarios. Purple bar: reference analysis; blue bar: BEQUAR members (average)

Finally, the differences in the risk picture amongst the BEQUAR members were quite evident both in terms of the absolute figure of risk and the relevance of the different Scenarios in contributing to the overall risk.

CONCLUSIONS

General Remarks

The focus of the benchmark described in this report was a reassessment, by independent reviewers, of an existing risk analysis. The selected chemical establishment used as the reference plant was an existing lower tier Seveso establishment. For the purposes of this exercise, a mock version of the original risk analysis was used. This mock version was generated by reworking the original data, assumptions and calculations used in the original safety report of the reference plant and "relocating" the plant to a different environment. These measures were specifically intended to avoid any possible correlation of the results of this benchmarking with the actual risks associate with the existing plant.

The participants in this benchmark study were a heterogeneous group, consisting of representatives of competent authorities from new Member States and candidate countries with responsibilities associated with implementation of the Seveso Directive in their countries. Risk analysis experts working in research organisations were also represented in this group. All risk experts were explicitly asked to provide their feedback at different steps of the risk analysis process not only as risk analysts, but also taking into consideration the particular perspective and concerns of the competent authorities within their country. Typically, the competent authorities have responsibility for evaluating whether the risk analysis is acceptable and also applying the information in executing associated risk management responsibilities, particularly land-use and emergency planning.

The main purpose of the benchmark study was to explore how independent evaluations by individual experts of the same risk analysis might differ in their findings and conclusions, and how these differences subsequently might influence the calculation of risk estimates associated with a particular zone of impact in the area surrounding the plant. By focusing the study on the evaluation of an already completed risk analysis, and its implications for a particular impact area, the benchmark study represented an approach to analysing risks of a chemical establishment closely aligned with the competent authority perspective. In this sense, the project differed significantly from previous benchmark studies coordinated by the JRC, that focussed on the independent execution of the risk analysis itself (rather than the review), by different teams of experts.

The following sections summarise the general conclusions of the benchmark study for the different steps of the risk analysis. It is however necessary to emphasise the fact that, for the purposes of providing a clear and concise summary, some positions taken by group members had to be simplified, requiring that some details and nuances were omitted. The conclusions presented here, therefore, represent a summary of general trends related to the different perceptions of members of the BEQUAR group on several aspects of the risks being evaluated. These conclusions do not pretend to provide an analysis, which is statistically significant.

Hazard Identification Analysis

The reference hazard identification analysis was considered as acceptable by the majority of the BEQUAR reviewers. There was some reluctance shared by a few concerning the lack of adequate details on possible mitigation actions. Regarding the credibility of Scenarios with high consequence/low probability character, the worst case Scenario (catastrophic rupture of the tank wagon due to collision with other tank) was debated the most in the group. However, it was broadly agreed that the competent authorities of their countries would require a detailed analysis of these Scenarios in any case regardless of their credibility. For all the other Scenarios there was a common agreement on the appropriateness of the Scenario description and on the assumptions made. The safeguards' description was considered satisfactory although some members suggested providing more details in the simplified HAZOP. Concerning events identified in the analysis as not having the potential to lead to an accident Scenario the group's level of agreement was relatively lower and members demonstrated a notable lack of confidence and indecision in regard to judging this aspect. This tendency was particularly evident for cases involving tank overpressure.

Frequency Data Review

The original data provided by the operator were taken as a basis for this analysis. However, some of the original data, assumptions and calculation methods were slightly modified by the JRC in order to differentiate the benchmark study from the actual case. In this way it was possible to produce a consistent data set that differed from the original analysis and, therefore, could be the object of an open and unconstrained review. By following this approach the project avoided being side-tracked by complications, and particularly confrontations with the original reference plant, related to possible misinterpretation of the data or disagreement on the methods used to calculate the frequencies of the top events. The review of the accident Scenario frequency data was conducted on a Scenario-by-Scenario basis.

For the sulphur dioxide tank wagon and all its Scenarios associated with the "*mission start*", the benchmark study members demonstrated a clear preference for higher accident frequency values. The group's response was notably homogeneous for the worst case Scenario (2 orders of magnitude higher) whilst a much greater variation in perspectives was observed for the other two Scenarios. A point to note is that these Scenarios were driven by human factors-related events, and for this reason, were considered by the benchmark study members as very difficult to assess. Such events tend to depend on a combination of several factors, for instance: (*i*) the specific instructions and procedures which are available and used in the plant and (*ii*) the specific safety culture within the organisation involved. Such elements are usually company/plant specific and evaluating the adequacy of this aspect of the risk analysis is very difficult for the competent authorities.

For the Scenarios related to the normal operation of the unloading of sulphur dioxide from the tank and that involve the failure of the three main components, that is, the flange, the flexible pipe, and the spring protection valve, in general the response was quite homogeneous amongst the benchmark participants. They also tended to prefer higher frequency values for these Scenarios. It is worth mentioning that the distribution of responses amongst the participants for the flexible pipe Scenario was much higher than for the other Scenarios, a fact attributable to the greater uncertainty associated with this type of component (which in turn is mainly due to the large variation in the data found in literature).

For ethanol related Scenarios the response of the members was quite uniform and in agreement with the reference value.

A point to note is that frequency assessment is a quite delicate task in any Quantitative Risk Assessment process. This situation results from the uncertainty associated with the data and the related effect on the final outcome of the overall risk analysis. For this reason, a fundamental step in the benchmark was to obtain feedback from the BEQUAR reviewers in terms of their perceptions about the appropriateness of the frequency values selected and particular challenges for reviewers in assessing whether the selected values are appropriate for the situation .

During discussions at the group's final meeting, the risk consultant who provided the frequency data for the reference plant's safety report argued that the frequency values proposed by some of the benchmark participants were often quite unrealistic and that the differences between their preferences and from the reference values actually used in some cases were extremely high. Moreover, he stated that in a number of instances their preferences could, probably not be validated by existing data sources, which implied that some members were making judgements solely on the basis of their subjective views rather than the objective evidence. Nonetheless, it was commonly recognised that, although the differences were perhaps a bit excessive for a few cases, uncertainty about frequency values is an ongoing and well known problem. What's more, the results of this discussion and the study as a whole only further confirmed that the lack of access to reliable reference databases for evaluating specific process hazards within the competent authorities is a significant obstacle to making informed judgments about the frequency assessments selected by the operators.

Consequence Assessment Review

As the benchmark was conducted under a competent authority perspective, the review of the consequence assessment was restricted to certain specific aspects. In particular, the analysis of the damage curves obtained through modelling of toxic gas dispersion and/or pressure/temperature distributions was excluded from the evaluation exercise. This effort would have required knowledge of all the codes used for modelling calculations, and these codes are not necessarily in the possession of most competent authorities. Rather, the review was carried out on: (*i*) the conclusions relative to the 'source terms' and (*ii*) the vulnerability assessment (*probit* values & threshold limits).

It was remarked by some countries that for risk analyses similar to that used in the benchmark exercise, , the worst-case Scenario (catastrophic rupture of the sulphur dioxide tank wagon) would be the only Scenario considered for full evaluation. In other countries, there would be an additional requirement to elaborate a consequence assessment for all selected Scenarios.

It was noted during the meeting discussions that no common methodology for consequence assessment is required in the majority of the new Member States or Candidate Countries. It is the operator who is responsible for selecting the methodology and the tools to be used. Moreover, the competent authorities are rarely in possession of the proper tools or knowledge to evaluate or perform consequence assessment calculations. For this reasons it was suggested that short-cut methods could be very useful for Competent Authorities in order to assess the consequence calculations in the safety report.

With regard to the calculation of the source terms, the majority of the benchmark study members considered that the calculations presented in the reference analysis were acceptable.

Concerning the vulnerability models used in the benchmark:

- For toxic related parameters, the benchmark responders did not show any specific preference for the proposed *probit* formulas. The same can be stated for the proposed threshold limits.
- For heat radiation a wide distribution of responses was noticed. Indeed, for *probit*, all the proposed formulas were the subject of comment; TNO and DNV were rated highest. The threshold limits selected by the different responders also varied quite significantly. Some of the reviewers also proposed some alternative values.
- For overpressure-related Scenarios, the *probit* formula of TNO was the definitive favourite. As a threshold limit, 1 bar was estimated to be the blast wave effect by the majority of responders.

Regardless of the preferred values or formulas, in general it was commonly agreed that all of them could be considered acceptable for safety report purposes. In addition, the discussions also acknowledged the ongoing diffiulty of which of the available formulas are the most reliable. For this reason, it was argued that a case-by-case approach should be followed for selecting the suitable model, influenced in particular by the type of potential impact predicted within each Scenario and the underlying assumptions. However, it should be noticed that the choice of a specific formula is often driven by practical factors such as, for instance, its availability in the literature or open sources.

In summary, the comments and discussions during the project highlighted the following interesting and important points concerning consequence assessment in the new Member States and Candidate Countries:

- The position of the competent authorities in the new Member States and Candidate Countries is more or less in line with what it is considered acceptable in the EU-15.
- By and large, no common methodology for consequence analysis has been strictly required in the new Member States. Moreover, the new Member States would gladly welcome further guidance in this field.
- The codes for performing modelling calculations are not broadly available. This situation is a further impediment for the competent authorities in effective implementation of their oversight responsibilities.

Risk Analysis Review

The modifications of the data suggested by each of the participants were each re-inserted into the modelling calculations to produce a corresponding re-calculation of the risk estimate for the impact area.   This exercise produced a number of different alternative risk estimates.

The differences between the estimates showed quite clearly the strong influence of the differences of opinion amongst the benchmark reviewers on the models and data that should be used . The final calculated risk estimates differed considerably, both in terms of the absolute risk number and the relevance of the different Scenarios in contributing to the overall risk.

Sulphur dioxide tank wagon

For the <u>sulphur dioxide tank wagon</u>, the estimated risks were generally higher than those presented in the reference risk analysis. This kind of difference might be attributable to the tendency of the benchmark study participants to assign higher accident frequency values for the different Scenarios, although that particular parameter did not seem to play a major role in quantitative terms in the overall case (with the single exception of the worst case Scenario).

In fact, the choice of the selected models for assessing the vulnerability played a much more critical role. When the most conservative models were used, the risk estimates were substantially different from the reference analysis.

The viewpoint of the benchmark study members also produced some marked differences from the reference analysis in regard to the way in which different Scenarios influenced the final risk estimate. In particular, some of the Scenarios considered totally negligible in the reference analysis were in fact still considered significant to the risk calculation by the benchmark reviewers.

Ethanol tanks

For the <u>ethanol tanks</u>, the calculation of risk estimates a potential pool fire or explosion using the various modified data suggested by the benchmark participants produced negligible results, very often smaller than the risk estimates calculated within the reference analysis.

As a final comment, considering the review as a whole, it should be emphasised that in this review took particular note of the influence of frequency data and of the vulnerability models on the final outcome of the risk analysis. For this reason the choice of these parameters was the subject of several discussions over the course of the project. Nonetheless, it was also demonstrated that other aspects, for example, reaction time, may play an important role in the overall risk analysis. Unfortunately, the significance of these aspects is not often immediately evident in the risk assessment process, and consequently, they are not often considered with the appropriate level of detail. To illustrate, reaction time did not attract much attention during the review of the data and assumptions but a sensitivity analysis of the final risk estimate clearly showed that the outcome is much more sensitive to the influence of this parameter than other parameters. In particular, a simulation was conducted assuming longer reaction times in comparison to the reference analysis (which was 20 minutes). This exercise demonstrated that the risk can be substantially augmented if, for whatever reason, the operator is delayed in taking appropriate corrective action beyond the normal expected time frame.

Final Remarks

All the participants recognised that the benchmark study had been an effective mechanism for identifying the weakness and strengths within their own country's strategy for reviewing the risk analyses of safety reports. The study created an active discussion platform, focussing on current practices and approaches use by the participating countries for analysing risk associated with Seveso-type establishments. Additionally, this approach allowed a productive exchange of information to take place amongst the participants on several aspects concerning the implementation of the Seveso Directive in their countries. In particular, this information exchange was highly valued by the study members given the recent entrance into force of the Directive in the new Member States and Candidate Countries.

In comparison to previous JRC benchmark exercises of this type, the current benchmark study showed a quite significant variation in the opinions of participants on individual elements. This variation was present for all the different steps of the risk analysis process. The main cause of the wide distribution of opinions was clearly associated with the intrinsic uncertainty of the risk analysis process.

In contrast to previous benchmark exercises, where different risk assessors performed their own independent analysis of the same reference establishment, the present benchmark consisted of independent reviews of the same risk analysis study. Notwithstanding the variation in opinion was not less significant than for previous studies.

The following comments were made during the final meeting discussions:

- Uncertainly is a key issue. All Scenarios classified as most dangerous have to be carefully analysed in order to manage uncertainty.
- Human factor analysis is an essential element and should be incorporated in any safety assessment study for Seveso purposes.
- The benchmark study showed that the overall risk estimate is very much influenced by the vulnerability model selected. The choice of this model is a crucial to the outcome of the analysis, as it is a main contributor to the uncertainty of the final result.
- On occasion the worst case Scenarios may receive too much scrutiny in proportion to their likelihood. The comparison between K111 and K121 is a good illustration of this problem, where the underlying assumptions were subjected to substantial discussion (e.g., reaction & repair times).
- Due to the intrinsic uncertainty associated with the risk analysis, the absolute value of the risk estimate is not necessarily the most important outcome of the overall process. Rather, the QRA framework necessitates a detailed analysis of the risk situation, which leads to a better understanding of the systems and processes involved and highlighting which are the critical elements.
- It should be noted that for very complex installations a full QRA could be very difficult to evaluate. The amount of information required can be significant and the

corresponding uncertainty associated with each parameter may therefore also be very difficult to estimate. Detailed guidance on how to evaluate a risk analysis study from a regulator’s standpoint would be extremely useful for the new Member States and Candidate Countries.

Finally the use of the ARIPAR software to improve the inter-comparability of the results, was considered to have added good value to the benchmarking process. A quantitative risk assessment application focusing on area risk where than risk associated with a single establishment, ARIPAR can produce inputs to risk management decisions that are highly specific concerning the risks and potential consequences associated with a particular area due to the presence of a particular activities and particular risk reduction solutions for that area.

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The authors are very grateful to all the benchmark study participants for their enthusiastic participation and technical input to this project without which the benchmark would not have been possible. Special thanks are expressed to the risk consultant who performed the original risk analysis study on the reference establishment. His technical contribution and his professional expertise were essential for the project execution.

Finally, the authors would like to express their gratitude to the management and the staff of the anonymous establishment used as the reference plant for this benchmark, for their continuous availability and very professional support.

APPENDIX I (HAZOP)

The present appendix gives the results of the HAZOP for the reference plant.

This was completed by the anonymous operator and the contracted consultancy company in charge of the risk analysis. All references to names have deliberately been eliminated.

For each top event, a first estimate of the risk has been given by using the risk matrix shown below.

	1 - SEVERITY	2 - SEVERITY	3 - SEVERITY	4 - SEVERITY
1 - LIKELIHOOD	1	2	3	4
2 - LIKELIHOOD	2	4	6	8
3 - LIKELIHOOD	3	6	9	12
4 - LIKELIHOOD	4	8	12	16

SEVERITY	Notes
1	In-site health injury or health impacts
2	In-site personal accidents or severe injury
3	Out-site death or severe lethal impacts
4	Out-site large number of death
LIKELIHOOD	Notes
1	Not accepted to occur during facility life
2	Could occur once during facility life
3	Could occur several times during facility life
4	Could occur on an annual basis (or more offen)
Risk Ranking Values (Risk Ranking)	Notes
1	In-site risk
2	In-site risk
3	Small and middle out-site risk
4	Small and middle out-site risk
6	Small and middle out-site risk
8	Large out-site risk
9	Large out-site risk
12	Large out-site risk
16	Large out-site risk

1. SULPHUR DIOXIDE

HAZOP meeting	Duration	Leader	Recorder	Present	
				Name	presence
1. 2002-12-13	4,00	Anonymous	Anonymous	Anonymous	Yes
				Anonymous	Yes
				Anonymous	Yes
				Anonymous	Yes
				Anonymous	Yes

Node: 1. Sulphur-dioxide tank wagon in the plant.	Drawing:
Type:	

1.1. Tank rupture

Causes	Consequences	Toxic Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR *				
1. Mechanic impact (hydrochloric acid or alkali tank wagon, once in every 2 -3 weeks).	1.1. 54 t SO2 release to the environment.	4	1	4			1.1. 54 t SO_2 release to the environment in the consequence of the catastrophic rupture of tank wagon. Tank temperature: 40 C^o; pressure: tension related to 40 C^o; height: 1.1 m; outflow to concrete surface, no bund.	

* S: Severity, L: Likelihood, RR: Risk Ranking

1.2. Isolable SO2 leakage on the pipe, before the pipefailure protector valve

Causes	Consequences	Toxic Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. Flange leakage.	1.1. Small amount of SO_2 release to the environment.	1	3	3	1.1. 8 pcs of SO2 sensor, 5 ppm sensitivity. 1.2. Presence of the operator crew, observes the leakage in 10 minutes and after fends the failure in 20 minutes.		1.1. Flange leakage of equivalent ø10 mm; horizontal outflow during 20 minutes (when SO_2 sensors are available) or during 30 minutes (when SO_2 sensors are not available); height: 5 m; pressure: tension related to 40 C^o.	1.1. The SO2 sensors' central unit is supplied and the 8 sensors are feeded from the central.

1.3. Isolable SO2 leakage on the flexible pipe.

Causes	Consequences	Toxic Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				

* S: Severity; L: Likelihood; RR: Risk Ranking

Causes	Consequences	S	L	RR	Protections	Safeguards	Scenario	Notes
1. Flexible pipe-end rupture and failure of the piperupture protector-valve.	1.1. Small amount of SO_2 release to the environment.	1	3	3	1.1. 8 pcs of SO2 sensor, 5 ppm sensitivity 1.2. Presence of the operator crew, observes the leakage in 10 minutes and after fends the failure in 20 minutes.		1.1. Flexible pipe-end rupture; vertical outflow from ø25 mm; during 20 minutes (when SO_2 sensors are available) or during 30 minutes (when SO_2 sensors are not available); height: 5 m; pressure: tension related to 40 C^o.	

1.4. Isolable SO2 leakage before the starch industry on the pipe bridge

Causes	Consequences	Toxic Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. Flexible pipe-end rupture and failure of the pipefailure protector- and the drain-valve.	1.1. Small amount of SO_2 release to the environment.	1	2	2	1.1. Presence of the operator crew, observes the leakage in 10 minutes and after fends the failure in 20 minutes.			1.1. Horizontal leakage at DN 25 mm at the height of 7 m for 30 minutes.

1.5. Not isolable SO2 leakage on the pipe, before the pipefailure protector valve

Causes	Consequences	Toxic Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. Flange leakage and the valve of the wagon is unlockable.	1.1. Great amount of SO_2 release to the environment.	2	2	4	1.1. 8 pcs of SO2 sensor, 5 ppm sensitivity 1.2. Presence of the operator crew, observes the leakage in 10 minutes and after fends the failure in 30 minutes.	1.Stopping the leakage is recommended on the spot, by mounting a flanged shutoff valve.	1.1. Flange leakage of equivalent ø10 mm; vertical outflow during 20 min. – immediately sensor signal, 20 min. for action (when SO_2 sensors are available) or during 30 min. – 10 min. for diagnosis, 20 min. for action (when SO_2 sensors are not available); and following that vertical outflow from ø40 mm during 10 minutes – mounting the shut-off valve height: 5 m; pressure: tension related to 40 C^o.	1.1.For the first 30 (10 + 20) minutes they are trying to fend the failure and after they mount a shutoff valve on the wagon in 10 minutes.

1.6. Not isolable SO2 leakage on the flexible pipe.								
Causes	Consequences	Toxic Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. Flexible pipe-end rupture and failure of the piperupture protector- and the drain-valve.	1.1. Great amount of SO_2 release to the environment	2	2	4	1.1. 8 pcs of SO2 sensor, 5 ppm sensitivity 1.2. Presence of the operator crew, observes the leakage in 10 minutes and after fends the failure in 30 minutes.	2. Stopping the leakage is recommended on the spot, by mounting a flanged shutoff valve.	1.1.Flexible pipe-end rupture; vertical outflow from ø25 mm; during 20 min. – immediately sensor signal, 20 min. for action (when SO_2 sensors are available) or during 30 min. – 10 min. for diagnosis, 20 min. for action (when SO_2 sensors are not available); and following that vertical outflow from ø40 mm during 10 minutes – mounting the shut-off valve; height: 5 m; pressure: tension related to 40 C^o.	1.1. For the first 30 (10 + 20) minutes they are trying to fend the failure and after mount the flanged hutoff valve on the wagon in 10 minutes.

1.7. nem kizárható SO2 kifújás a keményítő üzem előtti csőhídon								
Causes	Consequences	Toxic Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. Flexible pipe-end rupture and failure of the pipefailure protector- and the drain-valve and the valve of the wagon is not lockable.	1.1. Great amount of SO_2 release to the environment	2	1	2	1.1. Presence of the operator crew, observes the leakage in 10 minutes and after fends the failure in 30 minutes	5. Stopping the flow is recommended on the spot, by mounting a flanged shutoff valve.		1.1. Great amount of SO_2 release to the environment in vertical direction, at environmental temerapture, at atmospheric pressure at the height of 5 m, for 30 minutes at DN 25 mm, and after for 10 minutes at DN 40 mm.

1.8. Overpressure in the tank wagon								
Causes	Consequences	Toxic Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. Weather conditions and tank overheat.	1.1. SO_2 leak reaction for the pressure increase.	1	2	2	1.1. Tank wagons safety valve blows off.			1.1. 200 kg SO^2, in the tank wagon, temperature increase, 50 C^o

Node: 2. Sulphur-dioxide wagon change	Drawing:
Type:	
2.1. Tank rupture	

Causes	Consequences	Toxic Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. Mechanic impact	1.1. 54 t SO2 release to the environment.	4	1	4	1.1. Spragger and clearance protection.	3. It is recommended not to rack hydrochloric acid or alkali during wagon changing.	1.1. 54 t SO2 release to the environment to concrete surface at the height of 1.1 m, the temperature of the tank is 40 C° and the pressure tension relating to this temperature.	

2.2. not isolable SO2 release before the shut-off valve line

Causes	Consequences	Toxic Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. Flange or connecting fails and the drain-valve fails.	1.1. Great amount of SO_2 release to the environment.	2	2	4	1.1. Two persons are to ensure the process and they mount a flanged shutoff valve in 10 minutes.	4. The soonest intervention to stop the flow, by the locker armature, what is kept at the crew.	1.1. Vertical outflow from tank wagon valve flange ø40 mm during 10 minutes – mounting the shut-off valve; height: 5 m; pressure: tension related to 40 C° in the consequence of the tank wagon valve failure.	

2. ETHANOL STORAGE

Sessions Report				2003-02-23	
HAZOP meeting	Duration	Leader	Reporter	Present	
				Name	Presence
1. 2002-12-13	2,00	Anonymous	Anonymous	Anonymous	Yes
				Anonymous	Yes
				Anonymous	Yes
				Anonymous	Yes
				Anonymous	Yes
				Anonymous	Yes
Node: 1. 1-2-3-10 tanks				Drawing:	
Type:					
1.1. Catastrophic rupture.					

Causes	Consequences	Flammable Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. Material defect.	1.1. 5000 or 2000 or 930 or 230 m^3 alcohol release.	4	1	4	1.1. Bunds separetly are enough.		1.1. 5000 or 2000 or 930 or 230 m^3 alcohol release to the environment, environmental temperature, atmosferic pressure, in he consequence of the catastrophic rupture of the tank.	1.1. Bunds' area in order are: • 1: 1500 m^2 • 2. 817 m^2 • 3. 900 m^2 • 10. 100 m^2
2.Pipe branch rupture on a not isolatable section.	2.1. 5000 or 2000 or 930 or 230 m^3 alcohol release.	4	1	4	2.1. Bunds separetly are enough.	2. Planting of alcohol detectors, that are signing for a small amount also.	2.1. 5000 or 2000 or 930 or 230 m^3 alcohol release to the environment, at DN 80 mm at environmental temperature and atmosferic pressure. The discharge velocity depends on the hydrostatic head. Liquid levels in order are: 13.2m, 10m, 4.65m, 9.4m.	2.1. Bunds' area in order are: • 1100m2 • 617m2 • 700m2 • 10. 75m2 2.2. release times are: • 5000 m^3:45 óra • 2000 m^3: 21 óra • 930 m^3: 14 óra • 230 m^3: 2.5 óra
Overpressure in the tanks								

Causes	Consequences	Flammable Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				

1. Vacuum/pressure safety valve	1.1. Minimal overpressure in the tank	1	2	2	1.1.Resistance of the tankwall and the additional volume of the outward bulge			
	1.2. Minimal vacuum in the tank.	1	2	2	1.2. Resistance of the tankwall and the missing volume of the inward bulge			

1.3. Pressure decrease during unloading

Causes	Consequences	Flammable Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. Loss of power supply	1.1. small amount of alcohol release	1	1	1				

1.4. Rupture of pipe next to the tanks.

Causes	Consequences	Flammable Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. External mechanic impact (tree, truck, etc)	1.1. Small amount of alcohol release to the environment at NA 80 mm at the height of 6 m horizontally, max. 5 m^3 (the power of the pump is 15 m^3 per hour, 15 m high tank, 20 min. flow.).	1	1	1				

Node: 2. 6-7 tanks	Drawing:
Type:	

2.1. Catastrophic rupture

Causes	Consequences	Flammable Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. Material defect.	1.1. 700 m^3 alcohol release to the environment.	4	1	4	1.1. Bunds separetly are enough.		1.1. 700 m^3 alcohol release to the environment at evironmental temperature and pressure, in the consequence of the catastrophic rupture of the tanks NO. A/6 or A/7.	1.1. Bunds' area in order are: • 6. 113 m2 • 7. 113m2
2. Pipe branch rupture on a not isolatable section.	2.1. 700 m^3 alcohol release to the environment.	4	1	4	2.1. Bunds separetly are enough.	3. Planting of alcohol detectors, that are signing for a small amount also.	2.1. 700 m3 alcohol release to the environment, at DN 80 mm at environmental temperature and pressure, of the tanks No. A/6 or A/7. Liquid level: 8.9 m.	2.1 Bunds' area in order are: • 6. 34,5 m2 • 7. 34,5m2

2.2. Overpressure in tanks

Causes	Consequences	Flammable Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				

1. Vacuum/pressure safety valve.	1.1. Minimal overpressure in the tank.	1	2	2	1.1.Resistance of the tankwall and the additional volume of the outward bulge.			
	1.2. Minimal vacuum in the tank.	1	2	2	1.2. Resistance of the tankwall and the missing volume of the inward bulge.			

2.3. pressure decrees at the unloading

Causes	Consequences	Flammable Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. Loss of power supply.	1.1. Small amount of alcohol release.	1	1	1				

2.4. Rupture of the pipe next to the tanks

Causes	Consequences	Flammable Conseq.			Protections	Safeguards	Scenario	Notes
		S	L	RR				
1. External mechanic impact (tree, truck, etc).	1.1. alcohol release to the environment at DN 80 mm at the height of 6 m, horizontally max. 5 m^3 (the power of the pump is 15 m^3 per hour, 15 m high tank, 20 min. flow.)	1	1	1				

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