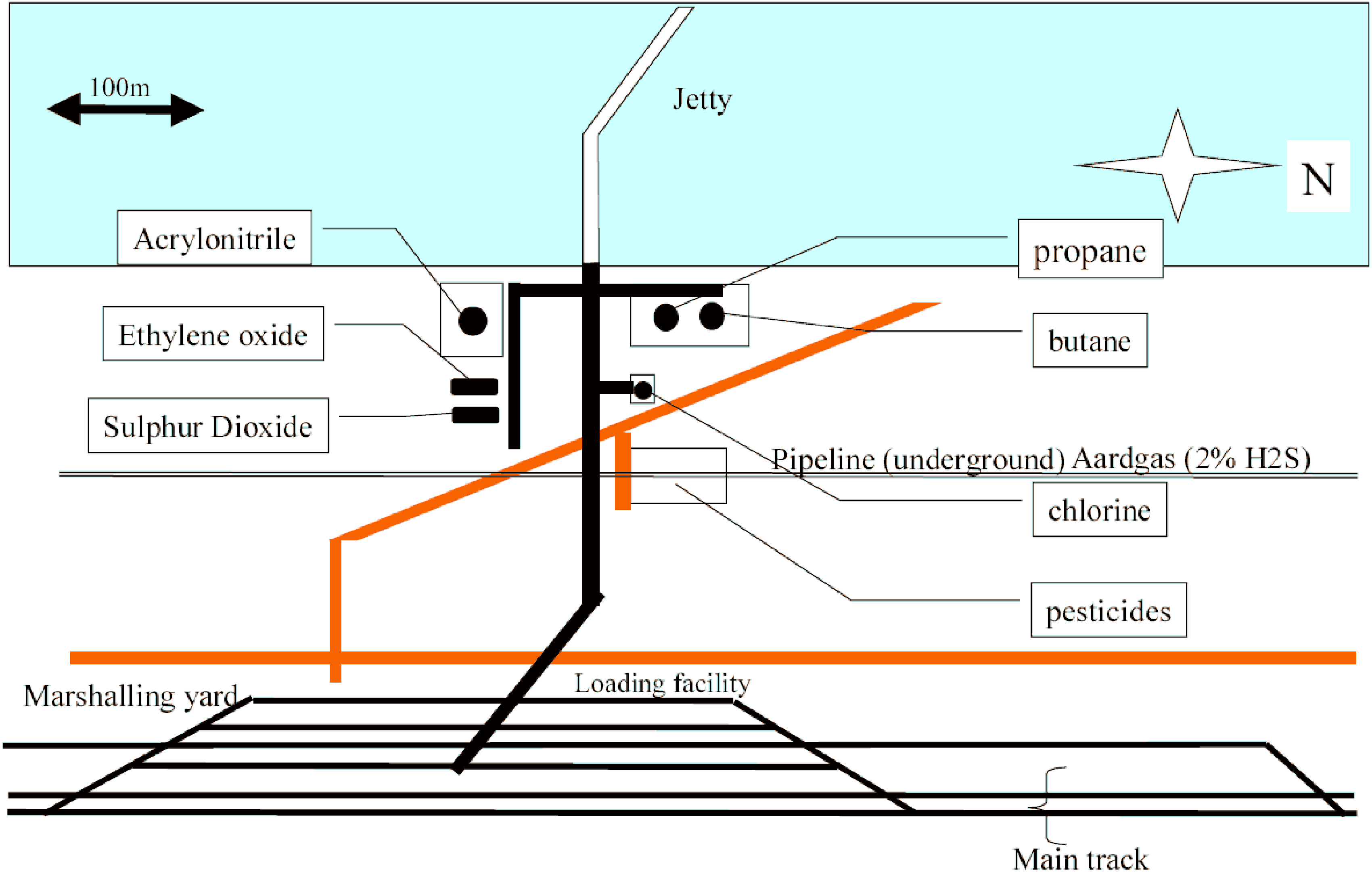
Appendix 2 The plant



RIVM Report 610066015/2001

Benchmark risk analysis models

B.J.M. Ale, G.A.M. Golbach[1], D. Goos[2], K. Ham[3], L.A.M. Janssen[4], S.R. Shield[5]

[1] AVIV, Enschede [2] DNV, Rotterdam [3] TNO/MEP Apeldoorn [4] SAVE, Apeldoorn

[5] Shell Global Solutions, Londen

Участники эксперимента

1 AVIV

AVIV is a consultancy bureau located in Enschede. It has some 15 years of experience in the field of risk analysis. It developed its own software, RISKCALC. AVIV uses this software and sells it. RISKCALC is a semi-automated system. The user has to define his own scenario's and attribute frequencies. Some manual operations are necessary to transfer data of the consequence analysis part to the risk calculation part.

2 DNV

The risk analysis consultants of DNV form an international subgroup of the larger DNV organisation. The participants in this exercise are located in Rotterdam. DNV has some 25 years of experience in this field. DNV developed several risk analysis packages. The predominant are PHAST and SAFETI. The latter product was used in the analysis. Although automated generation of failure cases is possible, in practice this is often done by hand by the analyst. After the definition of these cases the process is fully automated. PHAST and SAFETI are commercially available.

3 SAVE

SAVE is a consultancy bureau located in Apeldoorn. The bureau has some 20 years of experience. It developed its own software under the name of SAVEII. The software consists of separate consequence and damage modules that have to be run separately after the initial events have been generated by hand. SAVEII is commercially available.

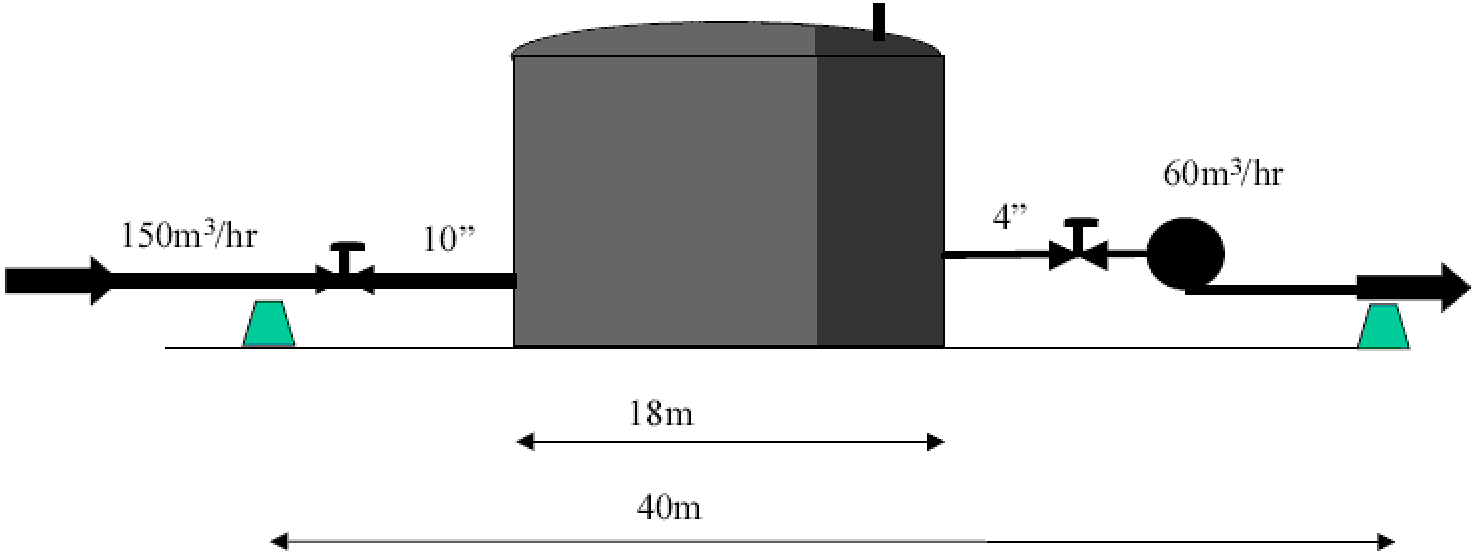
4 SHELL

Shell Global Solutions is a network of technology companies of the Royal Dutch / Shell Group, providing an integrated portfolio of services to companies inside and outside the group. With over 50 years of experience, the HSE Consultancy team covers the full spectrum of technical services within health, safety and the environment (HSE).

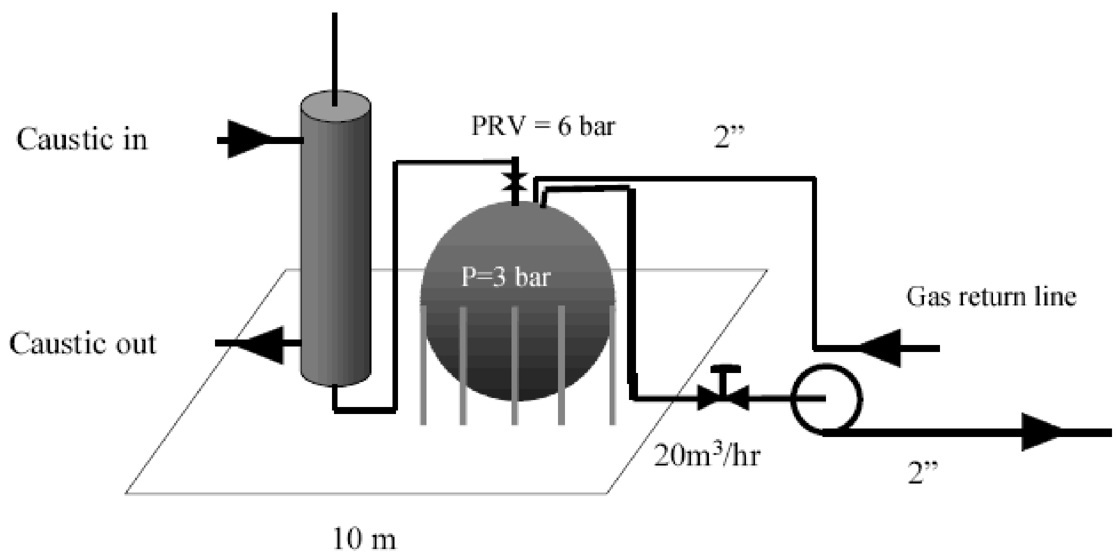
In recent years specialist software tools for hazard consequence modelling (FRED) and quantitative risk assessment (Shell Shepherd Desktop) were developed, based on in-house R&D and supported by full-scale experiments. These tools, previously only available within Shell, are now being made available to all companies.

5 TNO

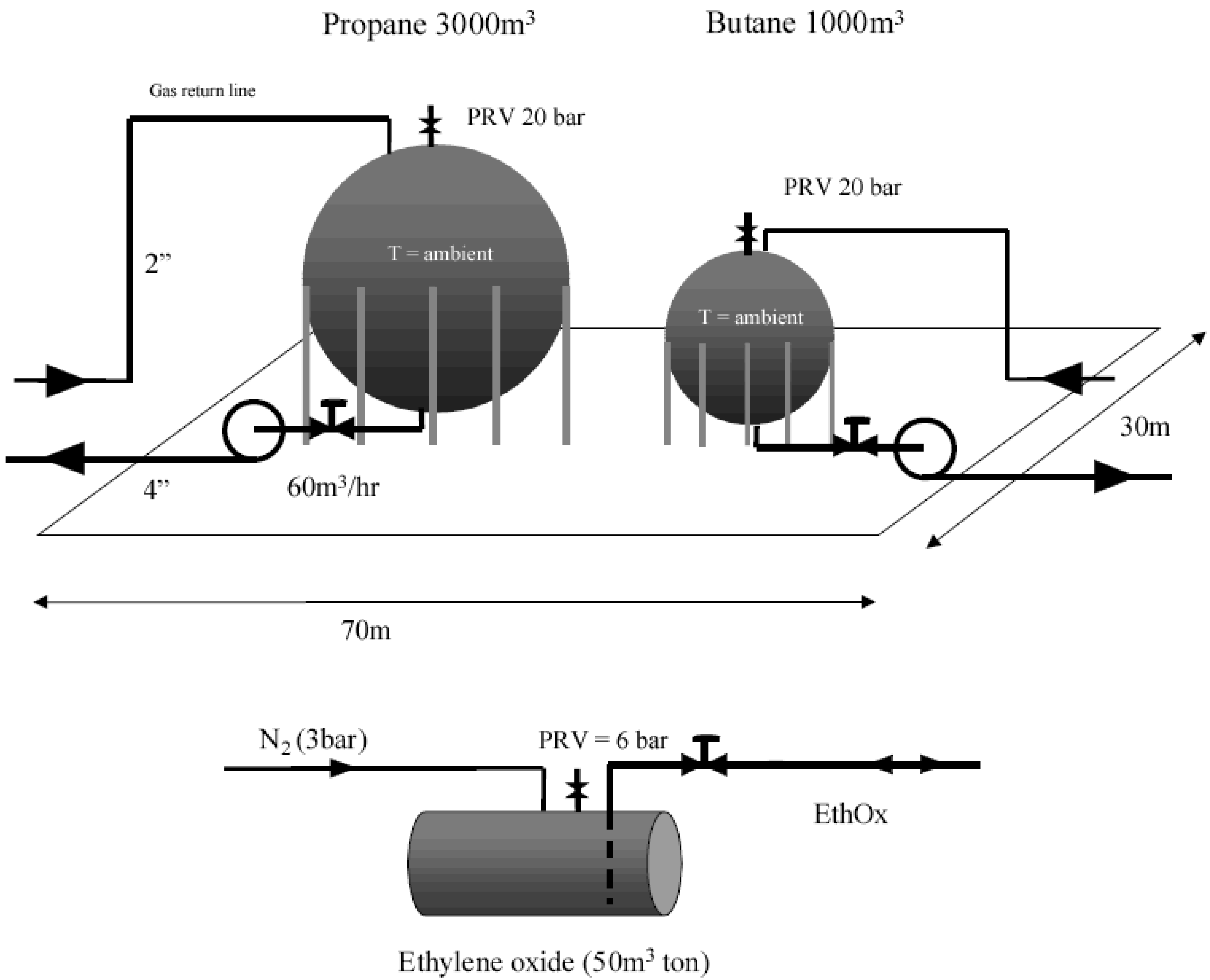
TNO/MEP is a group in the large TNO organisation. It has some 25 years of experience in quantified risk analysis. Of the four coloured books it produced two (the Yellow and the Green Book). TNO uses two software products EFFECTS, which is the software implementation of the Yellow Book and RISKCURVES, which uses the results of EFFECTS to generate risk numbers. EFFECTS is commercially available.



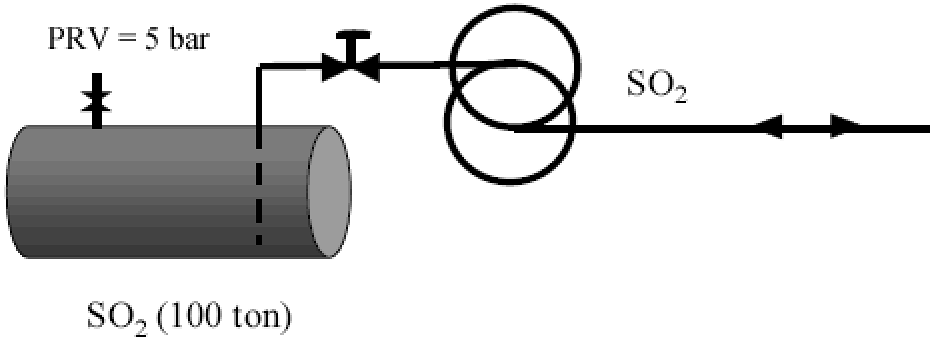
Хранилище акрилонитрила 3700 м3, 150 м3/час



Chlorine ($100m^3$)



Propane 3000m3
Butane 1000m3
Gas return line
PRV 20 bar
PRV 20 bar
T = ambient
T = ambient
2"
4"
60m3/hr
30m
70m
N2 (3bar)
PRV = 6 bar
EthOx
Ethylene oxide (50m3 ton)



Хранилище пестицидов 20*40*10 м3

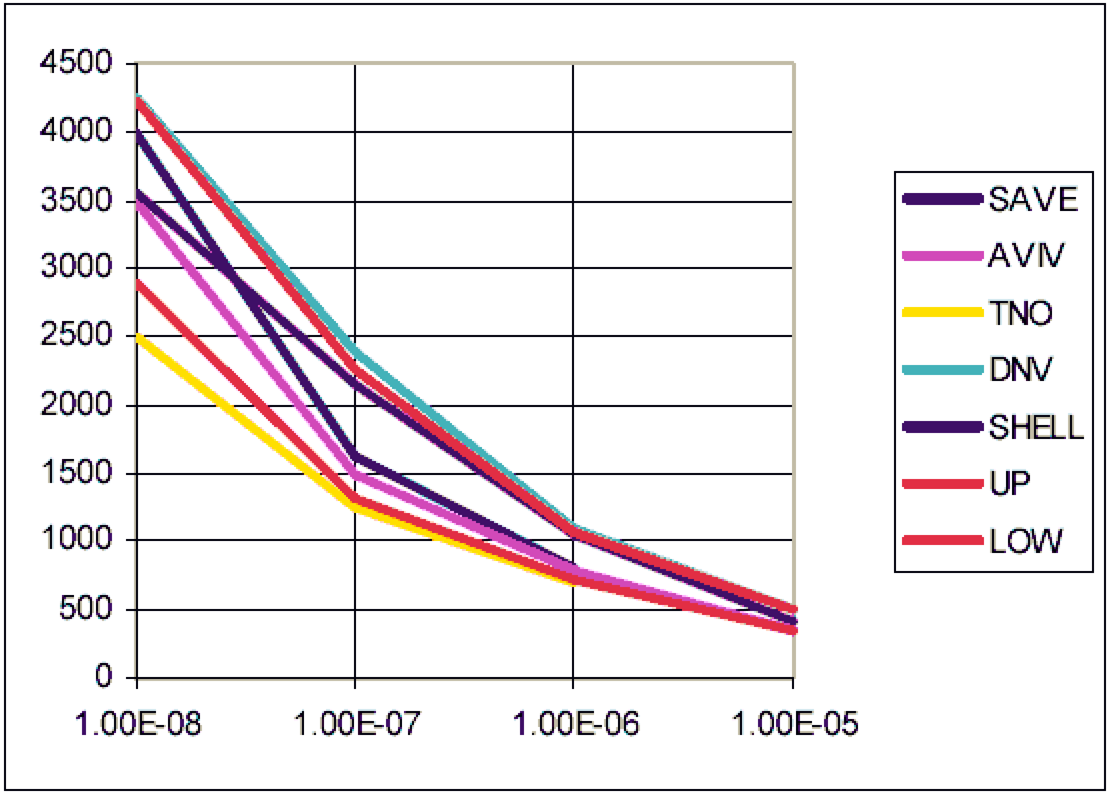
Трубопровод H2S D100 мм 15км P=12 атм

Система трубопроводов загрузки и отгрузки хлора, ACN, СУГ,SO2,C2H4O

Расстояние до границы уровня риска

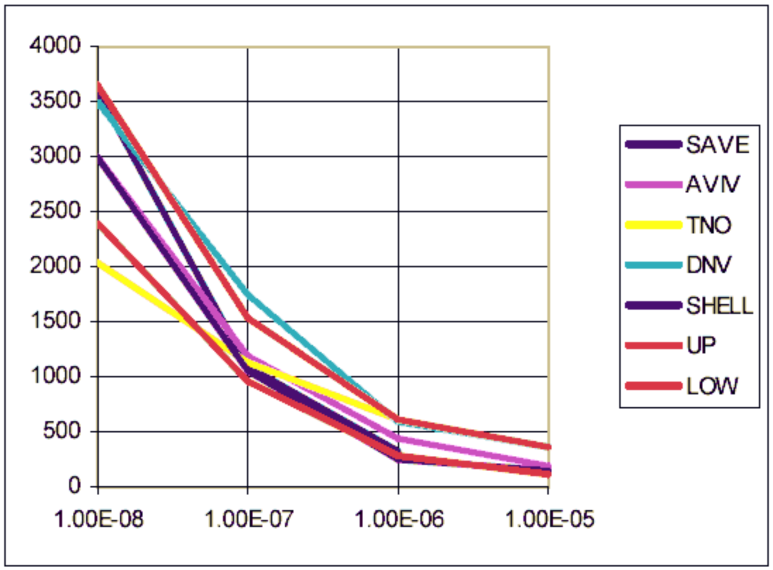
The whole site

	SAVE	AVIV	TNO	DNV	SHELL	UP	LOW	UP/LOW
1.00E-05		350		500	414	497	346	1.4
1.00E-06	810	800	710	1100	1053	1066	723	1.5
1.00E-07	1625	1500	1250	2400	2146	2259	1309	1.7
1.00E-08	4000	3500	2510	4250	3559	4230	2898	1.5



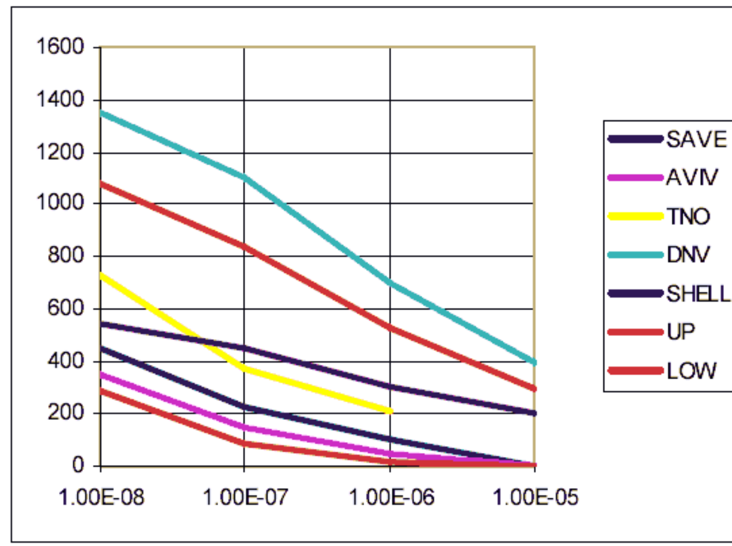
Marshalling yard

	SAVE	AVIV	TNO	DNV	SHELL	UP	LOW	UP/LOW
1.00E-05		200		375	150	360	124	3
1.00E-06	320	450	610	600	250	608	284	2
1.00E-07	1100	1200	1130	1750	1064	1533	964	2
1.00E-08	3600	3000	2030	3500	3003	3649	2405	2



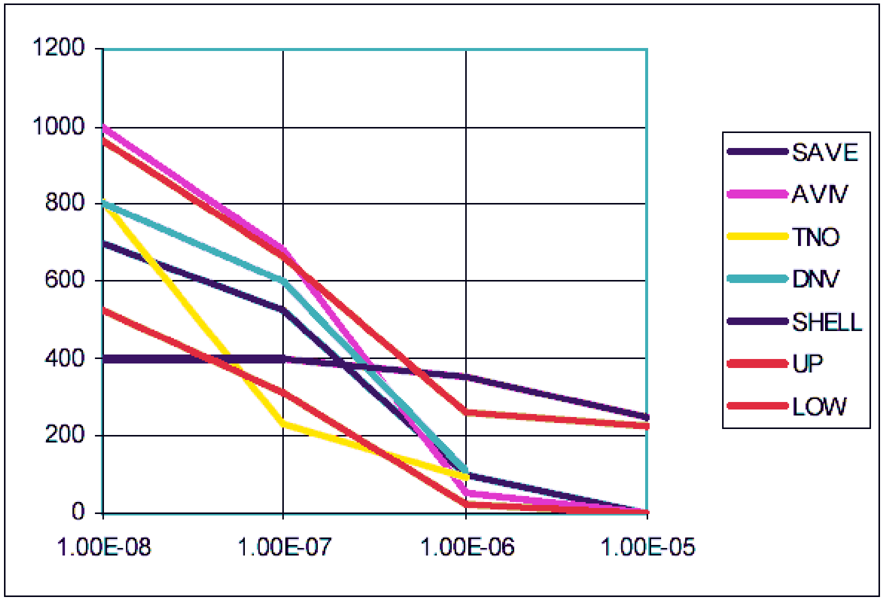
ACN

	SAVE	AVIV	TNO	DNV	SHELL	UP	LOW	UP/LOW
1.00E-05	0	0		400	200	299	0	
1.00E-06	100	50	210	700	300	530	14	38
1.00E-07	225	150	370	1100	450	836	82	10
1.00E-08	450	350	730	1350	546	1082	288	4



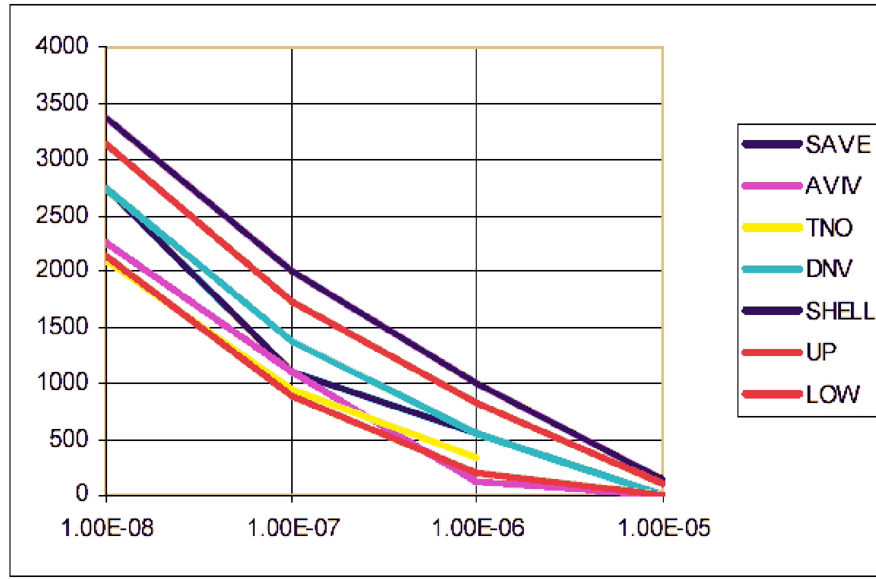
Butane

	SAVE	AVIV	TNO	DNV	SHELL	UP	LOW	UP/LOW
1.00E-05	0	0			250	228	0	
1.00E-06	100	50	90	110	350	260	20	13
1.00E-07	525	680	230	600	400	664	310	2
1.00E-08	700	1000	810	800	400	962	522	2



Chlorine

	SAVE	AVIV	TNO	DNV	SHELL	UP	LOW	UP/LOW
1.00E-05	0	0		0	130	98	0	
1.00E-06	550	125	340	550	991	832	190	4
1.00E-07	1100	1100	950	1375	1996	1720	888	2
1.00E-08	2750	2250	2090	2750	3364	3142	2140	1

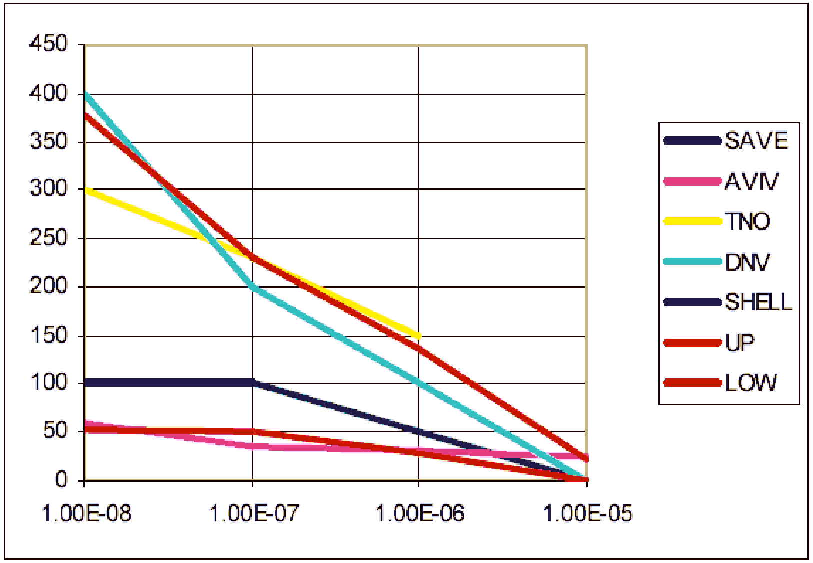


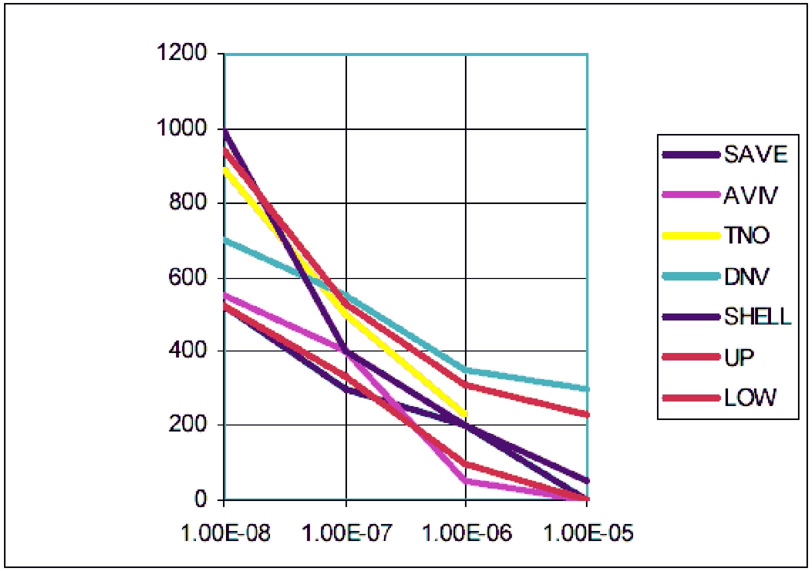
Pesticide storage

	SAVE	AVIV	TNO	DNV	SHELL	UP	LOW	UP/LOW
1.00E-05	0	25		0		23	0	
1.00E-06	50	30	150	100		136	29	5
1.00E-07	100	35	230	200		231	51	5
1.00E-08	100	60	300	400		377	53	7

SO_2

	SAVE	AVIV	TNO	DNV	SHELL	UP	LOW	UP/LOW
1.00E-05	0	0		300	50	231	0	
1.00E-06	200	50	230	350	200	313	99	3
1.00E-07	300	400	500	550	400	527	333	2
1.00E-08	525	550	890	700	996	939	525	2

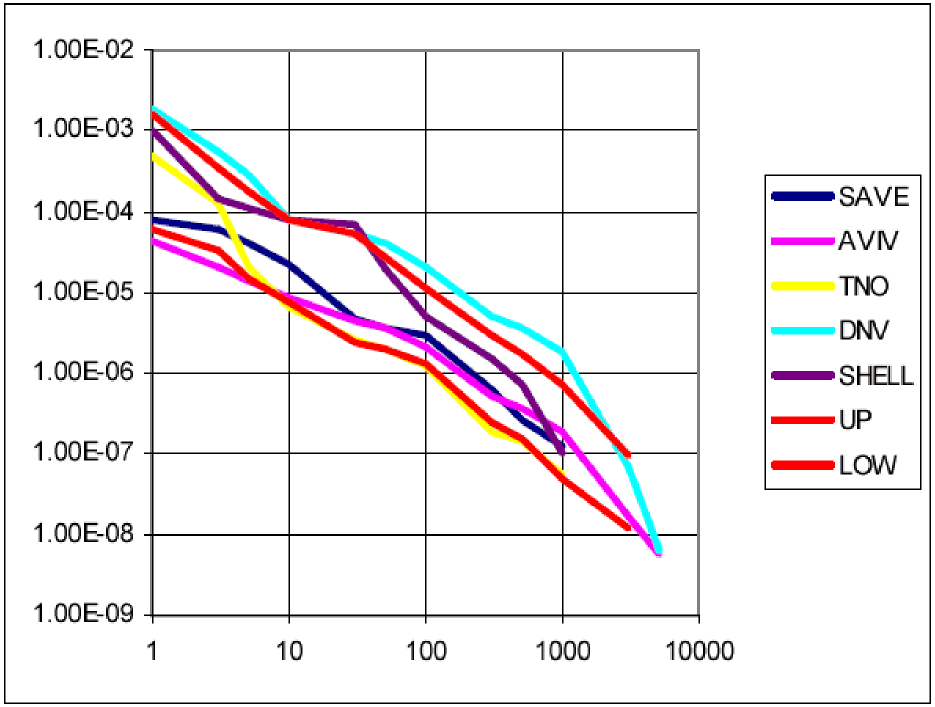




The whole establishment

Социальный риск

	SAVE	AVIV	TNO	DNV	SHELL	UP	LOW	ÚP/LOW
1	7.70E-05	4.31E-05	5.00E-04	1.90E-03	1.00E-03	1.62E-03	6.15E-05	26
3	6.20E-05	2.13E-05	1.28E-04	5.39E-04	1.50E-04	3.50E-04	3.24E-05	11
5	4.00E-05	1.36E-05	2.06E-05	2.85E-04	1.10E-04	1.77E-04	1.48E-05	12
10	2.20E-05	8.57E-06	6.66E-06	7.90E-05	8.00E-05	7.81E-05	7.36E-06	11
30	4.80E-06	4.34E-06	2.52E-06	5.33E-05	7.00E-05	5.40E-05	2.42E-06	22
50	3.50E-06	3.66E-06	1.93E-06	4.11E-05	2.00E-05	2.68E-05	1.98E-06	14
100	3.00E-06	2.07E-06	1.26E-06	2.05E-05	5.00E-06	1.11E-05	1.31E-06	8
300	6.30E-07	5.18E-07	1.87E-07	5.08E-06	1.50E-06	2.96E-06	2.48E-07	12
500	2.70E-07	3.60E-07	1.43E-07	3.55E-06	7.00E-07	1.74E-06	1.50E-07	12
1000	1.30E-07	1.88E-07	5.78E-08	1.87E-06	1.00E-07	7.36E-07	5.03E-08	15
3000		1.65E-08		6.92E-08		9.31E-08	1.23E-08	8
5000		5.90E-09		6.67E-09				
10000								



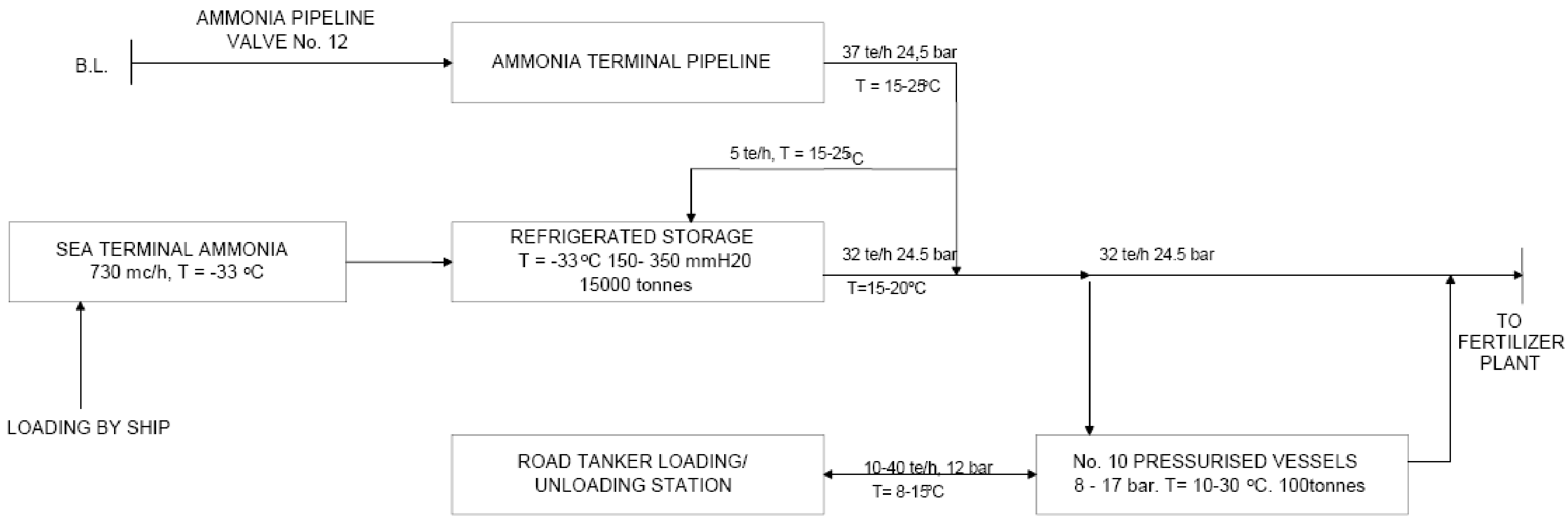
Risǿ -R-1344(EN) . Assessment of Uncertainties in Risk Analysis of Chemical Establishments. The ASSURANCE project . Final summary report

Kurt Lauridsen, Igor Kozine, Frank Markert
Aniello Amendola, Michalis Christou, Monica Fiori
Risǿ National Laboratory, Roskilde, Denmark

May 2002

- Det Norske Veritas Limited, UK
- INERIS, Fr
- Health and Safety Executive, Major Hazards Assessment Unit, UK
- NCSR DEMOKRITOS Systems Safety and Risk Assessment, GR
- TNO, Dept. of Industrial Safety, NL
- Universita di Bologna, DICMA, IT
- VTT Automation, FI
- The Joint Research Centre, Ispra
- Risǿ National Laboratory, DK

Схема потоков завода по хранению, приему и отгрузки аммиака



<u>Indicative distances between main components and pipeline lengths:</u>

Ship loading/unloading arm – Cryogenic tank: 900 m

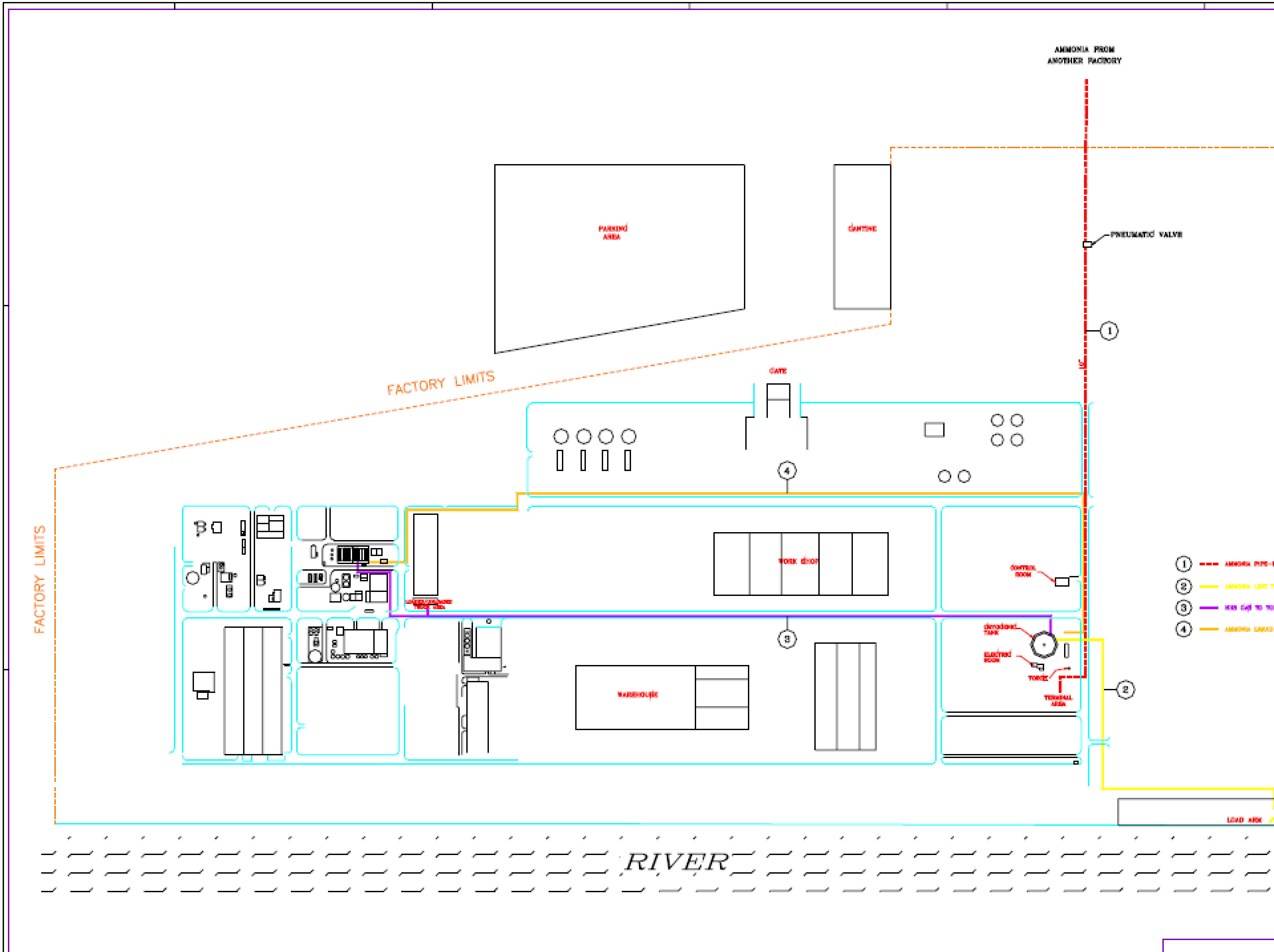
Cryogenic tank – Pipeline terminal: 50 m

Pipeline Valve 12 – Pipeline terminal: 966 m

Cryogenic tank – Pressurised storage area: distance=1200m, pipework=1500m

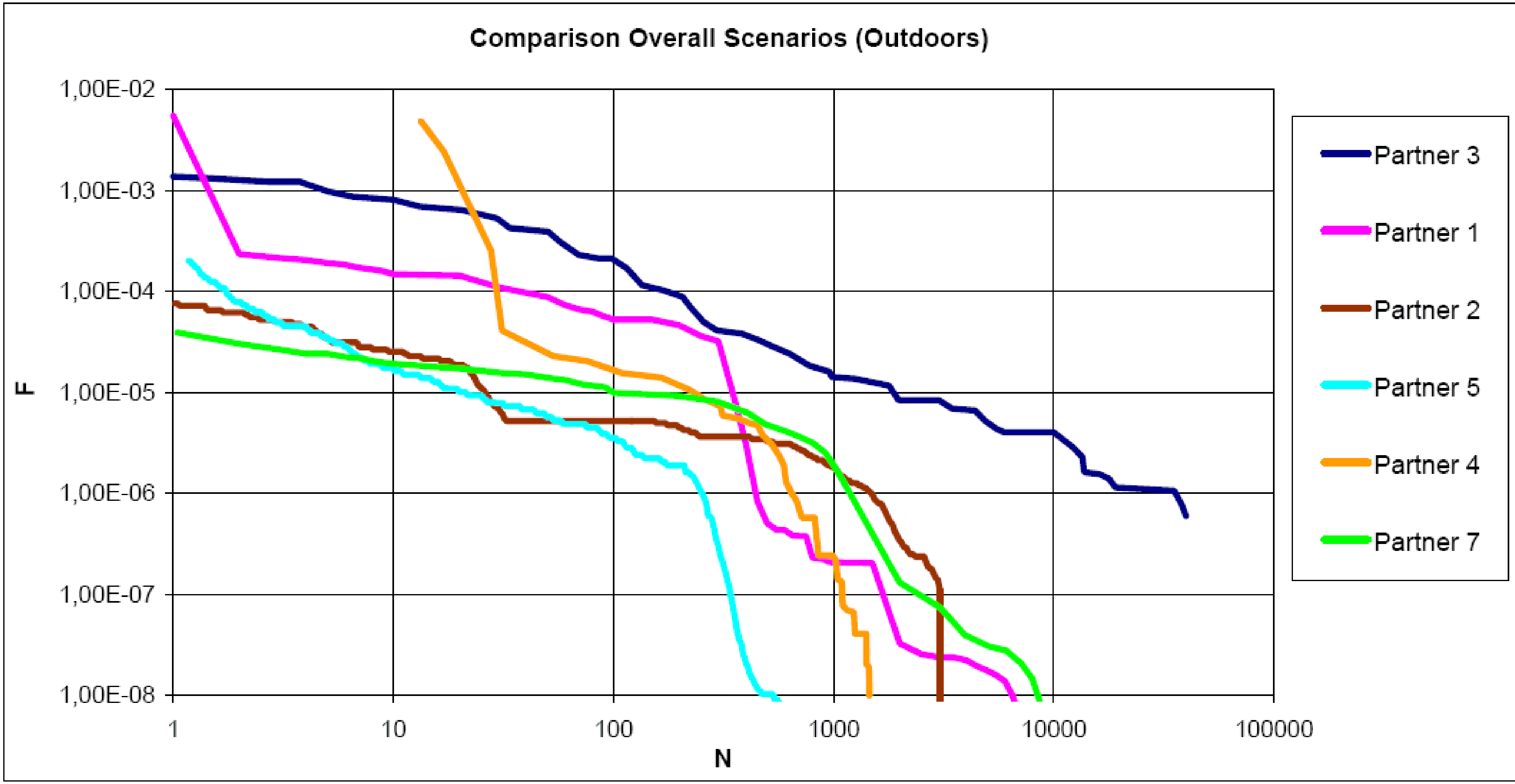
Cryogenic tank – Flare: 20m (flare at a height of 45m)

Pressurised storage area – Trucks loading/unloading facility: 200 m.



AMMONIA FROM
ANOTHER FACTORY
PNEUMATIC VALVE
PARKING
AREA
CANTINE
FACTORY LIMITS
FACTORY LIMITS
GATE
WORK SHOP
WAREHOUSE
LOAD AREA
RIVER

Расхождение в полях индивидуального риска для уровня 10E-5 в год (минимальное и максимальные расстояния от объекта).



Расхождения в оценке социального риска для фиксированного распределения Населения региона

Table 1 Frequencies of the top events of the common scenarios used by the partners (events per year)

		Partner number							
#	**Top Event***	**3**	**4**	**1**	**5**	**7**	**2**	**6**	**Range of deviation**
1	Major ammonia leak from 8'' feeding pipe	2.1 10^{-4}	5.0 10^{-6}	9.5 10^{-5}	1.6 10^{-5}	2.0 10^{-5}	7.7 10^{-6}	3	5.0 10^{-6} - 2.1 10^{-4}
2	Breakage of 4'' pipe 241P-067-P1349	3.9 10^{-4}	1.0 10^{-4}	2.0 10^{-4}	5.9 10^{-5}	7.3 10^{-4}	4.5 10^{-4}	2	5.9 10^{-5} - 7.3 10^{-4}
4	Rupture or disconnection between ammonia ship and unloading arm 241-ME1	5.8 10^{-3}	5.0 10^{-3}	4.8 10^{-4}	4.1 10^{-6}	1.0 10^{-5}	4.8 10^{-4}	4	4.1 10^{-6} - 5.8 10^{-3}
7	Rupture of 10'' pipe 241P-089-P1283	4.0 10^{-4}	2.0 10^{-8}	3.9 10^{-8}	7.0 10^{-5}	1.7 10^{-4}	-------	2	2.0 10^{-8} - 4.0 10^{-4}
7*	Rupture of a ship tank	5.7 10^{-5}	------	2.3 10^{-7}	2.3 10^{-6}	4.9 10^{-6}	2.3 10^{-7}	-------	2.3 10^{-7} - 5.7 10^{-5}
9	Rupture of cryogenic tank 241-S1	Contained leak: 1.0 10^{-6} Uncontain leak: 4.0 10^{-8}	------	5.0 10^{-7}	5.0 10^{-8}	5.0 10^{-7}	1.0 10^{-8}	4	1.0 10^{-8} - 1.0 10^{-6}
10	Rupture of 20'' pipe 241P-015-P1284	9.0 10^{-5}	1.0 10^{-6}	7.6 10^{-6}	8.8 10^{-7}	9.7 10^{-7}	1.0 10^{-6}	2	8.7 10^{-7} - 9.0 10^{-5}
14	Rupture of one of the ten pressurised tanks	2.5 10^{-6}	5.0 10^{-7}	1.6 10^{-6}	1.3 10^{-5}	2.0 10^{-6}	5.0 10^{-7}	3	5.0 10^{-7} - 1.3 10^{-5}
15	Rupture of 4'' pipe on the distribution line of tank 241-V1	2.3 10^{-4}	2.0 10^{-5}	6.0 10^{-5}	1.1 10^{-5}	4.9 10^{-7}	3.4 10^{-8}	2	3.4 10^{-8} - 2.3 10^{-4}
17	Rupture or disconnection between ammonia truck and unloading arm	3.7 10^{-3}	6.0 10^{-5}	4.7 10^{-6}	6.8 10^{-5}	1.0 10^{-6}	1.5 10^{-7}	1	1.5 10^{-7} - 3.7 10^{-3}
18	Catastrophic rupture of a truck tank	2.3 10^{-7}	1.2 10^{-7}	1.1 10^{-8}	7.4 10^{-9}	2.7 10^{-8}	1.5 10^{-9}	1-2	1.5 10^{-9} - 2.3 10^{-7}

- Grey tanned cells contain the lower assessments. Black tanned cells contain the upper assessments

Table 2 Assumptions related to the frequency assessments of pipelines

#	Top Event	Assumptions	Partner 3	Partner 4	Partner 1	Partner 5	Partner 7	Partner 2
1	Major ammonia leak from 8'' feeding pipe	Length (m)	10 (above ground)	50	966	850 (800 undergro-und, 50 above)	1000	966
		Utilisation factor	8000/8760	1	1	1	1	1
		Piping-related components		valves	valves	None	Valves	valve
		Failure causes: 1. Mechanical $(m \cdot y)^{-1}$	1.0 E-7	}	9.85 E-8	} 1.1 E-7, above	2.0 E-8	}
		2. Overpressure		} 1.0 E-7	Not quantifiable	} 1.3 E-8, under		} 1.0 E-7
		3. Extern. impact	✗ (dominates)	}	Included in 1	} ground		}
2	Breakage of 4'' pipe 241P-067-P1349	Length (m)	5	1000	500	800	1500	1500
		Utilisation factor	8000/8760	1		1	1	1
		Piping-related components				1 valve (7.3 E-8)	Valves included	valve
		Failure causes: 1. Mechanical $(m \cdot y)^{-1}$	1.0 E-7	}	3.0 E-7	}	5.0 E-7	}
		2. Overpressure		} 1.0 E-7	E-4 (both sides)	} 7.3 E-8		} 3.0 E-7
		3. Extern. impact	✗ (dominates)	}	Included in 1	}		}
7	Rupture of 10'' pipe 241P-089-P1283	Length (m)	10	100	900	800	900	Not provided
		Utilisation factor	8000/8760	20/8760	1/100 ev/y, duration 24 h	1	1	
		Piping-related components	Flanges included			None	Valves included	
		Failure causes: 1. Mechanical $(m \cdot y)^{-1}$	1.0 E-7	1.0 E-7	1.0 E-7	}	2.0 E-7	
		2. Overpressure			✗	} 8.8E-8		
		3. Extern. impact	✗ (dominates)		Included in 1	}		
10	Rupture of 20'' pipe 241P-015-P1284	Length (m)	20	10	25	20	25	10
		Utilisation factor	1	1	1	1	1	1
		Piping-related components				None	Valves included	valve
		Failure causes: 1. Mechanical $(m \cdot y)^{-1}$	1.0 E-7	}	1.0 E-7	}	4.0 E-8	}
		2. Overpressure		} 1.0 E-7	✗	} 4.4E-8		} 1.0 E-7
		3. Extern. impact	✗	}	Included in 1	}		}
	Rupture of 4'' pipe on the distribution line of tank 241-V1	Length (m)	20	200	200	50	6	200
		Utilisation factor	1	1	1	1	1	5/8760
		Piping-related components				None	Valves included	valve
		Failure causes: 1. Mechanical $(m \cdot y)^{-1}$	1.0 E-7	}	3.0 E-7 (=)	}	8.0 E-8	}
		2. Overpressure		} 1.0 E-7		} 2.2E-7		} 3.4 E-8 (=)
		3. Extern. Impact	✗	}	Included in 1	}		}
			Factor 5 to adapt generic frequenc					

Notation "(=)" means that the source of the frequencies was the same but different numbers were taken, "✗" means that a failure cause was considered and its frequency quantified

Table 3 Assumptions related to the frequency assessments of loading arms

#	Top Event	Assumptions	Partner 3	Partner 4	Partner 1	Partner 5	Partner 7	Partner 2
4	Rupture or disconnection between ammonia ship and unloading arm 241-ME1	Number of transhipments (yr^{-1})	5		8	6	6	8
		Failure causes: 1. Mechanical ($trship^{-1}$)	1.0 E-5 yr^{-1}		6.0 E-5 (extr incl.)		1.0 E-5 yr^{-1} (1.6 E-6/operation/yr)	
		2. Overpressure	4.0 E-4 yr^{-1} (judg)	5.0 E-3	✗	6.8E-6 per cargo		6.0 E-5
		3. Other	✗ (dominates)					
17	Rupture or disconnection between ammonia truck and unloading arm	Number of transhipments (yr^{-1})	10	10	20	10	20	10
		Failure causes: 1. Mechanical	1.0 E-6 (pipe 2", 5 m)		3.0 E-8 (1/h)		1.0 E-6 yr^{-1} (5.0 E-8/operation/yr)	
		2. Overpressure		6.0 E-5	✗ (from truck)	6.8E-6 per		3.0 E-8
		3. Other	✗ (dominates)			delivery		

Table 4 Assumptions related to the frequency assessments of tanks

#	Top Event	Assumptions	Partner 3	Partner 4	Partner 1	Partner 5	Partner 7	Partner 2
9	Rupture of cryogenic tank 241-S1	Failure causes: 1. Mechanical	Insignificant (double wall structure)		5.0 E-7 (=)	5.0 E-8	5.0 E-7	
		(yr^{-1}) 2. Overpressure	1.0 E-6	1.5 E-4	✗			1.0 E-8 (=)
		3. Extern. impact						
			Spilling outside the	Rupture only of	Tank with protec-	Double	Tnk with outer	Full containment
			concrete wall 0.04	Tank roof	tive outer shell	containment tank	containment	tank
						No breach of bund		
14	Rupture of one of the ten pressurised tanks	Failure causes: 1. Mechanical	5.0 E-7		5.0 E-7	1.3 E-5		
		(yr^{-1}) 2. Overpressure		5.0 E-7	✗	6.5E-6 per vessel	2.0 E-6	5.0 E-7
		3. Extern. impact	✗		Included in 1			
		Utilisation factor	2 tanks in use	1 tank in use	3 tanks in use	2 tanks in use		1 tank in use
			Estimate for a single					
			tank					
18	Catastrophic rupture of a truck tank	Number of transhipments (yr^{-1})	20 (0.4% of time, i.e. 30 hrs/yr)	10 (15 hrs/yr)	2.28 E-3 (20 transh per yr, 8 h each transhipment)	10	20 (60 hours per year)	10 (truck is 45 min on-site)
		Failure causes: 1. Mechanical	8.6 E-9		5.7 E-11 (1/h)		2.7 E-8/yr (1.4 E-9/ delivery)	
		(yr^{-1}) 2. Overpressure	✗	1.2 E-7	✗	6.5E-6		1.5 E-9
		3. Extern. impact	✗		Included in 1			Including traffic acc
7*	Rupture of a ship tank	Number of transhipments (yr^{-1})	5.4 (average)	Not provided	8	5	6	8
		Failure causes: 1. Ship-Jetty				2.1 E-7 per cargo	5.0 E-6/yr (8.3 E-7/ operation)	3.0 E-8 per cargo
		2. Ship-ship collision	5.0 E-7 per cargo		3.0 E-8 per cargo	2.6 E-7 per cargo		
		3. Fires and explosion	1.0 E-5 per cargo			0		

Notation "(=)" means that the source of the frequencies was the same but different numbers were taken

Table 5 Recalculated frequencies according to the assumptions common for all research teams

#	Top Event*	Partner number 3	4	1	5	7	2	6	Range of deviation
1	Major ammonia leak from 8'' feeding pipe	$4.6\ 10^{-6}$	$9.0\ 10^{-7}$	$9.0\ 10^{-7}$	$1.0\ 10^{-6}$	$1.8\ 10^{-7}$	$9.0\ 10^{-7}$	3	$1.8\ 10^{-7}$ - 4.6×10^{-6}
2	Breakage of 4'' pipe 241P-067-P1349	$1.4\ 10^{-5}$	$9.0\ 10^{-7}$	$1.0\ 10^{-5}$	$7.3\ 10^{-7}$	$4.6\ 10^{-6}$	$2.7\ 10^{-6}$	2	$7.3\ 10^{-7}$ - $1.4\ 10^{-5}$
4	Rupture or disconnection between ammonia ship and unloading arm 241-ME1	$8.0\ 10^{-3}$	$5.0\ 10^{-3}$	$4.8\ 10^{-4}$	$5.4\ 10^{-5}$	$1.3\ 10^{-5}$	$4.8\ 10^{-4}$	4	$1.3\ 10^{-5}$ - $8.0\ 10^{-3}$
7	Rupture of 10'' pipe 241P-089-P1283	$4.6\ 10^{-6}$	$9.0\ 10^{-7}$	$1.0\ 10^{-6}$	$8.0\ 10^{-7}$	$1.8\ 10^{-6}$	-------	2	$8.0\ 10^{-7}$ - $4.6\ 10^{-6}$
7*	Rupture of a ship tank	$5.7\ 10^{-5}$	------	$2.3\ 10^{-7}$	$2.3\ 10^{-6}$	$4.9\ 10^{-6}$	$2.3\ 10^{-7}$	-------	$2.3\ 10^{-7}$ - $5.7\ 10^{-5}$
9	Rupture of cryogenic tank 241-S1	$4.0\ 10^{-8}$	------	$5.0\ 10^{-7}$	$5.0\ 10^{-8}$	$5.0\ 10^{-7}$	$1.0\ 10^{-8}$	4	$1.0\ 10^{-8}$ - $5.0\ 10^{-7}$
10	Rupture of 20'' pipe 241P-015-P1284	$5.0\ 10^{-6}$	$9.0\ 10^{-7}$	$6.0\ 10^{-6}$	$4.0\ 10^{-7}$	$4.0\ 10^{-7}$	$1.0\ 10^{-6}$	2	$4.0\ 10^{-7}$ - $6.0\ 10^{-6}$
14	Rupture of one of the ten pressurised tanks	$1.0\ 10^{-6}$	$4.5\ 10^{-7}$	$1.0\ 10^{-6}$	$1.3\ 10^{-5}$	$4.0\ 10^{-7}$	$1.0\ 10^{-6}$	3	$4.5\ 10^{-7}$ - $1.3\ 10^{-5}$
15	Rupture of 4'' pipe on the distribution line of tank 241-V1	$1.5\ 10^{-5}$	$9.0\ 10^{-7}$	$3.0\ 10^{-6}$	$2.2\ 10^{-6}$	$8.0\ 10^{-7}$	$3.4\ 10^{-7}$	2	$3.4\ 10^{-7}$ - $1.5\ 10^{-5}$
17	Rupture or disconnection between ammonia truck and unloading arm	$2.1\ 10^{-3}$	$2.7\ 10^{-6}$	$2.4\ 10^{-6}$	$6.0\ 10^{-6}$	$5.0\ 10^{-7}$	$1.5\ 10^{-7}$	1	$1.5\ 10^{-7}$ - $2.1\ 10^{-3}$
18	Catastrophic rupture of a truck tank	$1.2\ 10^{-7}$	$1.2\ 10^{-7}$	$5.5\ 10^{-9}$	$4.7\ 10^{-6}$	$1.4\ 10^{-8}$	$1.5\ 10^{-9}$	1-2	$1.5\ 10^{-9}$ - $4.7\ 10^{-6}$

- Grey tanned cells contain the lower assessments. Black tanned cells contain the upper assessments

* More detailed definition of top events for the common scenarios can be found in ANNEX I

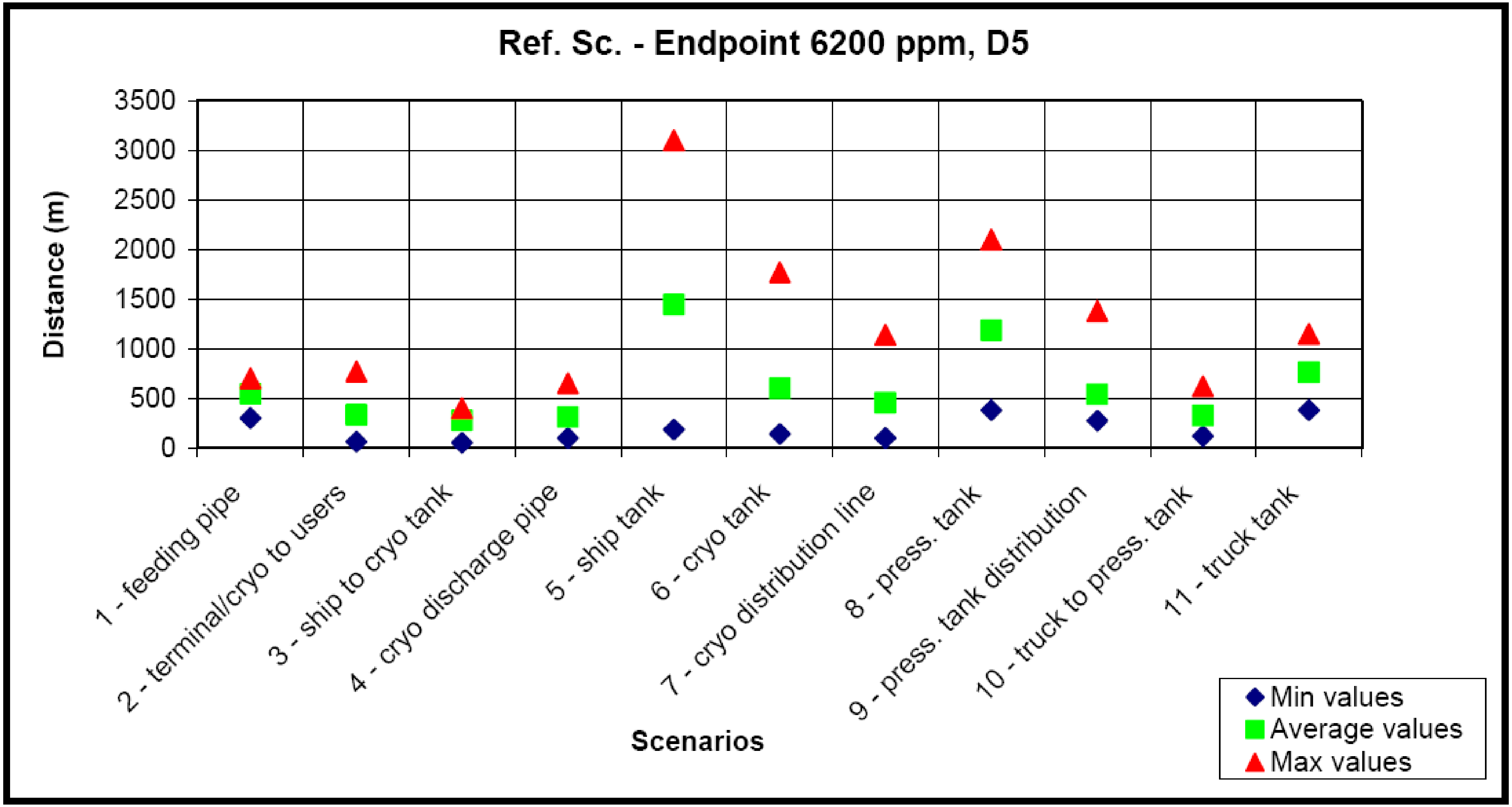


Figure 9 Variation of results for the consequence assessment of the reference scenarios. Minimum, maximum and average values for concentration endpoint of 6200 ppm (LC1%)

Figure 10. Discrepancy in the results of individual risk calculations relevant to risk-informed Land Use Planning: Maximum and minimum distances for the isorisk curve 10^{-5} yr^{-1} (same figure as Figure 3)

Table 10. Variation in the average radius for Isorisk Curves 10^{-5} and 10^{-6} yr^{-1}

	Average radius for 10^{-5} yr^{-1} Individual Risk Curve		**Average radius for 10^{-6} yr^{-1} Individual Risk Curve**	
PARTNER	**Radius(m)**	***Deviation from Average (%)***	**Radius(m)**	***Deviation from Average (%)***
Partner 1	565	-8.13	1325	12.36
Partner 2	125	-79.67	925	-21.56
Partner 3	1310	113.01	1676	42.13
Partner 4	545	-11.38	820	-30.46
Partner 5	530	-13.82	1150	-2.48
Partner 7	/*		/*	
Average	*615*	*R=384 (62.46%)*	*1179.2*	*R=304 (25.79%)*

* Results of Partner 7 are not comparable to the others

Findings concerning hazard identification

- Many different approaches / variants for hazard identification have been used
- Hazard identification is done using a combination of complementary approaches
- Three groups of approaches could be distinguished:

-Methods based on a *top-down analysis, mainly represented by the Master Logic Diagram, having a form similar to fault trees, starting from a top event and going down to combinations of basic events, capable to provoke accident;*

-Methods based on a *bottom-up analysis, like HAZOP, SWIFT, HAZSCAN and HCA, which investigate whether deviations of the process variables and failures of individual devices can provoke a major accident; and*

-Methods based on the systematic identification of the possible release events, mostly supported by use of *checklists or based on national standards, after division of the plant in areas.*

- For several partners the definition and risk labelling of the categories used in the screening and ranking of identified hazards vary from project to project. No predefined categories are used.
- The understanding of what e.g. “catastrophic event” or "likely event" means differs from partner to partner. Therefore, great care has to be taken not to introduce misunderstandings using labels in discussions among experts or in risk communication to the public.
- The strategies to define consequence categories are rather different ranging from the application of release times, release rates, total releases and consequence lengths. Comparing these, a very good correlation for these categories is found. Nevertheless, only using release rates to categorise may lead to larger differences in the screenings.

- The severity of the scenarios is assessed using an evaluation matrix defined by the categories for the frequencies and the consequences. In order to select the most important scenarios relevant for quantification the risk matrix is reduced. This is in most cases done by cutting off the scenarios in the lowest consequence category regardless the value of the frequency. In the second step, the next lowest consequence category combined with the lowest frequency category is also reduced.
- The scenarios with very low probability are preserved in the highest consequence categories. Some partners, furthermore, emphasise the importance of the consequences using marking.
- The scenarios selected by the partners differ substantially in detail, but the most important hazardous events were identified by all participants.

Findings concerning frequency assessments

Pipelines (Scenarios 1, 2, 7, 10 and 15)

The range of deviation in the frequency assessments of pipelines' failures reaches up to 4 orders of magnitude (Scenario 7 and 15). Causes of the deviation revealed are:

1. Different length of pipe sections considered in the frequency calculations.
2. Ignoring the utilisation factor taking into account a part-time involvement of some of the plant parts.
3. The use of different generic data sets for the assessments of failure frequencies.
4. Disagreement on what failure frequency is more relevant as a generic reference data (the same data source but different numbers).
5. Different failure causes considered.
6. Ignoring piping-related components (valves, flanges and pumps).
7. The use of a correction factor to allow for vibration, corrosion, thermal stresses etc. (some partners use the factor, the other does not).

Loading arms (Scenario 4 and 17)

The range of deviation in the frequency assessments of loading arms' failures reaches up to 4 orders of magnitude (Scenario 17). Causes of the deviation revealed are:

1. Slight difference in the number of transhipments (least contribution to uncertainty)
2. Different failure causes considered.
3. The use of different generic data sets for the assessments of failure frequencies.

Tanks (Scenario 7*, 9, 14 and 18)

The range of deviation in the frequency assessments of tanks' failures reaches up to 2 orders of magnitude (Scenario 7*). Causes of deviation revealed are:

1. Slight difference in the number of transhipments (least contribution to uncertainty)
2. Different failure causes considered.
3. Different understanding or interpretation of the design applied
4. Disagreement on what failure frequency is more relevant as a generic reference data (the same data source but different numbers).
5. The use of different generic data sets for the assessments of failure frequencies.

Findings concerning consequence assessments

General sources of uncertainty:

- Knowledge on some scenarios seems not to be consolidated yet (e.g. scenario 5 – Rupture of a ship tank and release of refrigerated ammonia on the sea surface. Although all partners foresee a partial dilution of ammonia into the water and partial evaporation, the relevant percentages vary significantly).
- The uncertainty (or ambiguity) in definition of scenarios is the main source of uncertainty for the catastrophic rupture of the cryogenic tank
- Lower variation in the results was observed for most of the scenarios referring to pipeline ruptures.
- There was a "state-of-knowledge" problem for the feeding pipeline, which is a very long one, and the models usually employed do not apply in this particular case.

Uncertainties in the calculation of outflow for pipes connected to pumps:

- Assumptions related to the characteristic curve of the pump and pumping against zero pressure
- Use of models not-tailored to model the particular release (e.g. hypothetical tank with constant pressure)
- Simplifications related to the consideration of release from one or from two sides of the ruptured pipe.
- Length of the pipe
- Time of reaction (closure of valves)

Uncertainties in the calculation of outflow for pipes connected to tanks:

- Level of liquid in the tank
- Discharge factor Cd
- Length of the pipe
- Time of reaction (closure of valves)

Uncertainties in the calculation of outflow rate for tanks

- Definition of the scenario
- Level of liquid in the tank
- Dimensions and position of the rupture
- Initial conditions (overpressure)
- Instantaneous release of the initial vapour, for refrigerated ammonia

Uncertainties concerning pool formation and evaporation

- Assumptions related to the violence of the phenomenon. These assumptions determine t
he percentage of droplets in the cloud and its overall behaviour in the dispersion phase.
- Percentage of droplets
- Type of ground assumed. Especially in the case of release on water the variation in the results is very large.
- Structure and characteristics of the models applied, both for pool formation and for evaporation (whether they take into consideration heat exchange from sun, air, etc.)

Uncertainties concerning dispersion

- Source terms.
- Interface between models.
- Initial behaviour of the cloud, i.e. whether a passive dispersion or dense-gas dispersion model should be applied.
- The detailed characteristics of the dispersion model.

Uncertainties concerning Dose/Response calculation

- Form and coefficients of the probit function

Table 11 Summary of key results from reference scenarios

Reference scenario	Frequency range yr^{-1}		Ratio between frequencies	Release rate kg/s		Raito between release rates	Released amount kg		Ratio between released amounts	6200 ppm conc. endpoint, m (F2-weather conditions)		Ratio between endpoints
	Min	Max		Min	Max		Min	Max		Min	Max	
Pressurised pipelines												
1	1,8E-07	4,6E-06	26	25	280	11,2	3000	84900	28	200	1850	9
2	7,3E-07	1,4E-05	19	9,5	150,7	15,9	2412	90000	37	150	1434	10
15	3,4E-07	1,5E-05	44	30	239	8,0	9000	71700	8	400	1275	3
Pressurised tanks												
14	4,00E-07	1,30E-05	33	-	-		-	-		570	3800	7
18	1,50E-09	4,70E-06	3133	-	-		-	-		320	2200	7
Refrigerated pipelines												
7	8,00E-07	4,60E-06	6	94	300	3,2	28500	180000	6	80	3466	43
10	4,00E-07	6,00E-06	15	1100	2500	2,3	47400	750000	16	250	3201	13
Refrigerated tanks												
9	1,00E-08	1,00E-06	100	-	-		-	-		250	4755	19
7*	2,30E-07	5,70E-05	248	-	-		-	-		65	10000	154
Loading arms												
4	1,30E-05	8,00E-03	615	139	210	1,5	16680	126000	8	118	2300	19
17	1,5E-07	2,1E-03	14000	7	62	8,9	1404	18600	13	200	680	3

Table 12 Qualitative assessment of the importance of various factors to the uncertainty in the calculated risk (the more stars the more important)

Factor	Importance
Differences in the qualitative analysis[5]	**
Factors relating to frequency assessment:	
Frequency assessments of pipeline failures	***
Frequency assessments of loading arm failures	****
Frequency assessments of pressurised tank failures	****
Frequency assessments of cryogenic tank failures	***
Factors relating to consequence assessment:	
Definition of the scenario	*****
Modelling of release rate from long pipeline	***
Modelling of release rate from short pipeline	*
Release time (i.e. operator or shut-down system reaction time)	***
Choice of light, neutral or heavy gas model for dispersion	****
Differences in dispersion calculation codes	***
"Analyst conservatism" or judgement	***