Storage of Technical (Porous) Ammonium Nitrate at Yara plant in Köping, Sweden

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Introduction

During the last years, Ammonium Nitrate has been involved in several accidents worldwide. This have caused increased focus on security and safety issues and resulted in:

- Revised Yara standards
- Revised international standards for storage and transportation
- Stricter regulations from national authorities in many countries
- Established Industry Workgroup to study storage requirements for Technical AN.

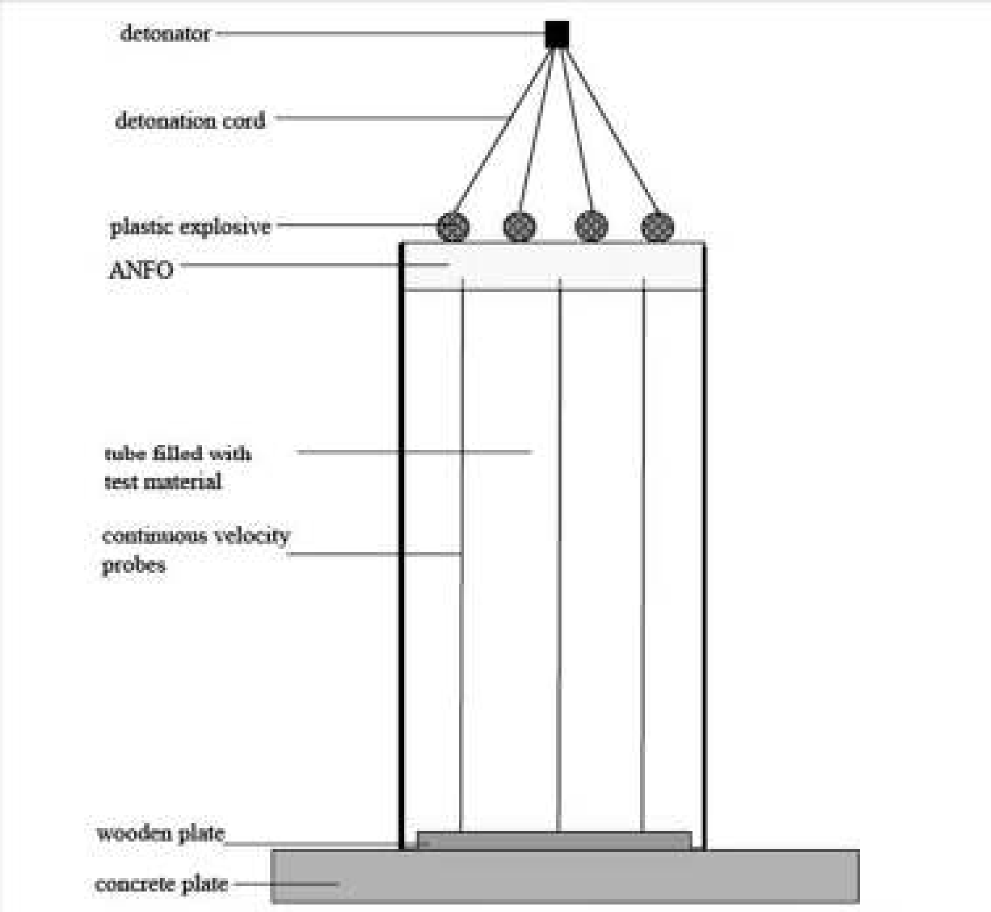
Objectives

The main objectives of this study were to verify safety aspects and to optimise the storage layout for porous Technical Ammonium Nitrate (TAN) at our production site in Köping, Sweden.

- Determine guidelines for the separation distances between stacks of big bags and between silos.
- Calculate the maximum storage amount based on the maximum allowable overpressure for facilities, storages, silos and residential areas.
- Risk assessment of TAN storages
- Calculate effect of debris on the surroundings

Detailed results from the detonation tests were presented in my paper at the EFEE conference in Vienna in 2007

Tube Test



- Tube dimensions; L=4 m (13 ft, diameter=1.16 m (46 inches)
- Test material: approx 3.5 tons
- 300 kg ANFO booster (initiated by 3 rings of HE)
- Velocity probes to measure detonation velocity
- Free field blast measured in two directions (angle of 90°)

Tube test: Set-up

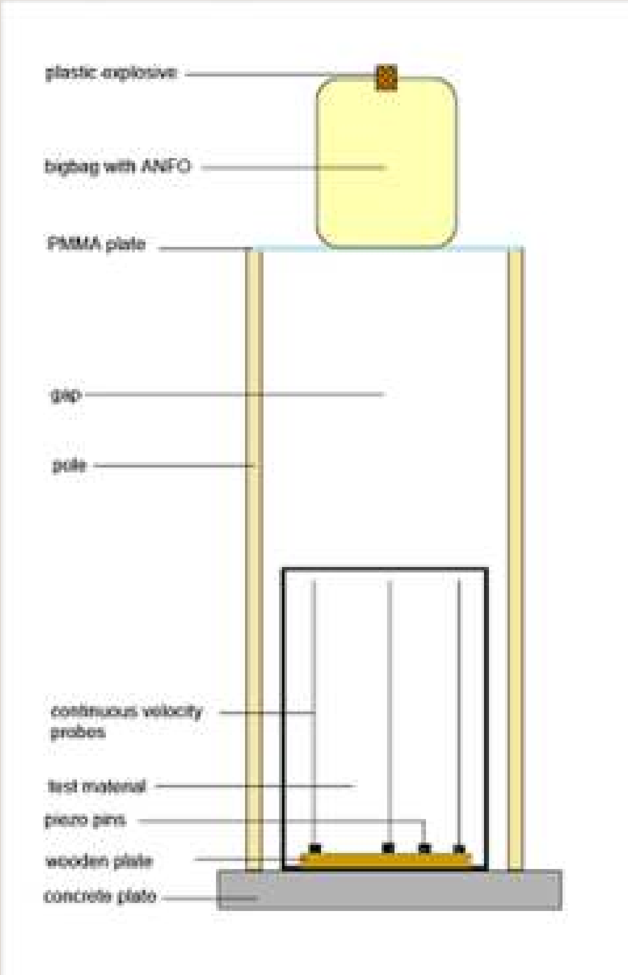
Results: Velocity of detonation and TNT equiv.

Test material	Loading density (in test tube) kg/l	Detonation velocity km/s	Theoretical velocity of detonation (Cheetah calc) km/s	TNT Equivalence @40 m / @160m
TAN1	0.84	3.98	3.74	0.57 / 0.49
TAN2	0.82	3.97	3.66	0.55 / 0.35
TAN3	0.72	3.56	3.44	0.57 / 0.45

Comments TNT Equivalence

- TNT equivalences in the present tests are relatively high compared to the values calculated from incidents (10 – 20 % TNT equivalence).
- Most measurements at short distance and not compensated for ideal configuration/shape
- **<u>In the interpretation of the equivalence value it must be kept in mind that the tests were fully optimised with respect to configuration and very strong initiation source.</u>**
- In previously performed experiments with fertilizer grade AN (TNO for EFMA) it was also found that the TNT equivalence is decreasing when the distance is increasing.

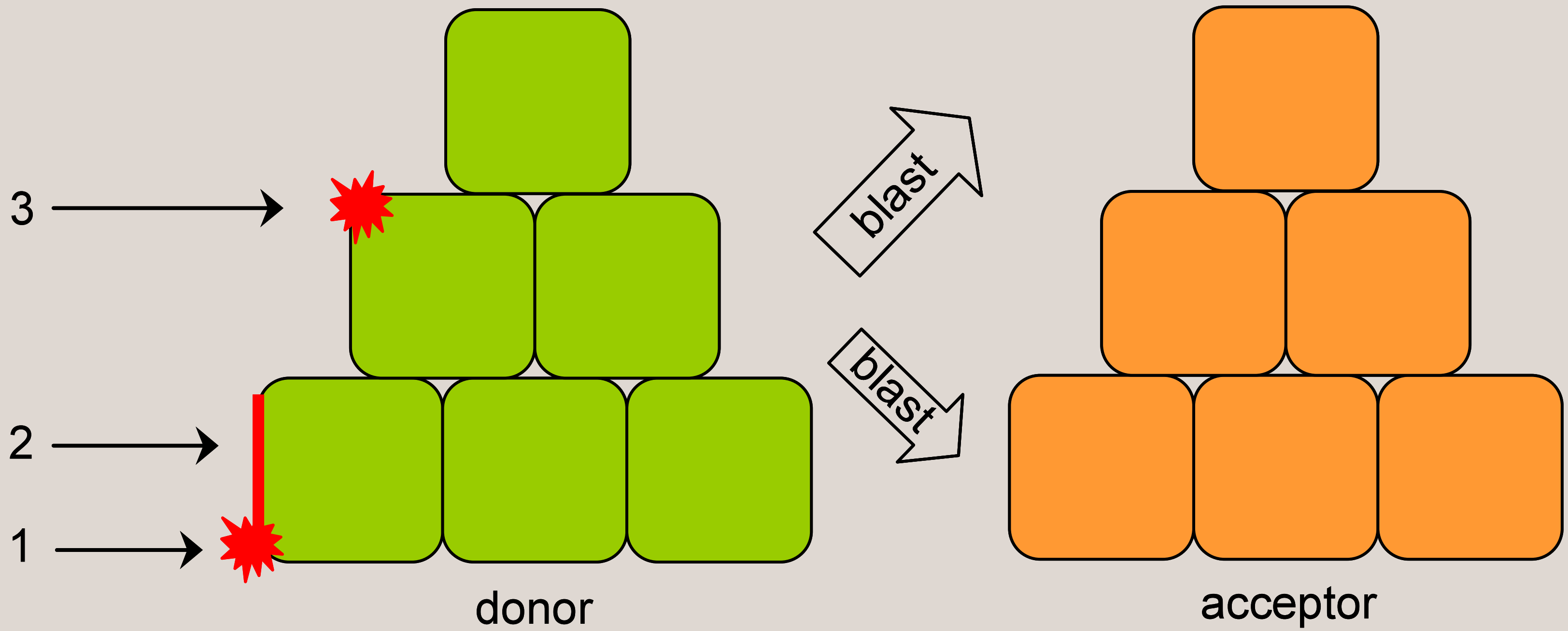
GAP Test: Setup



Results, GAP Test

Material	Critical gap length [m]	Critical initiation pressure [GPa]
TAN 1	2.0-2.5	0.47-0.35
TAN 2	1.75-2.5	0.56-0.34
TAN 3	2.5-3.0	0.34-0.26

Simulations

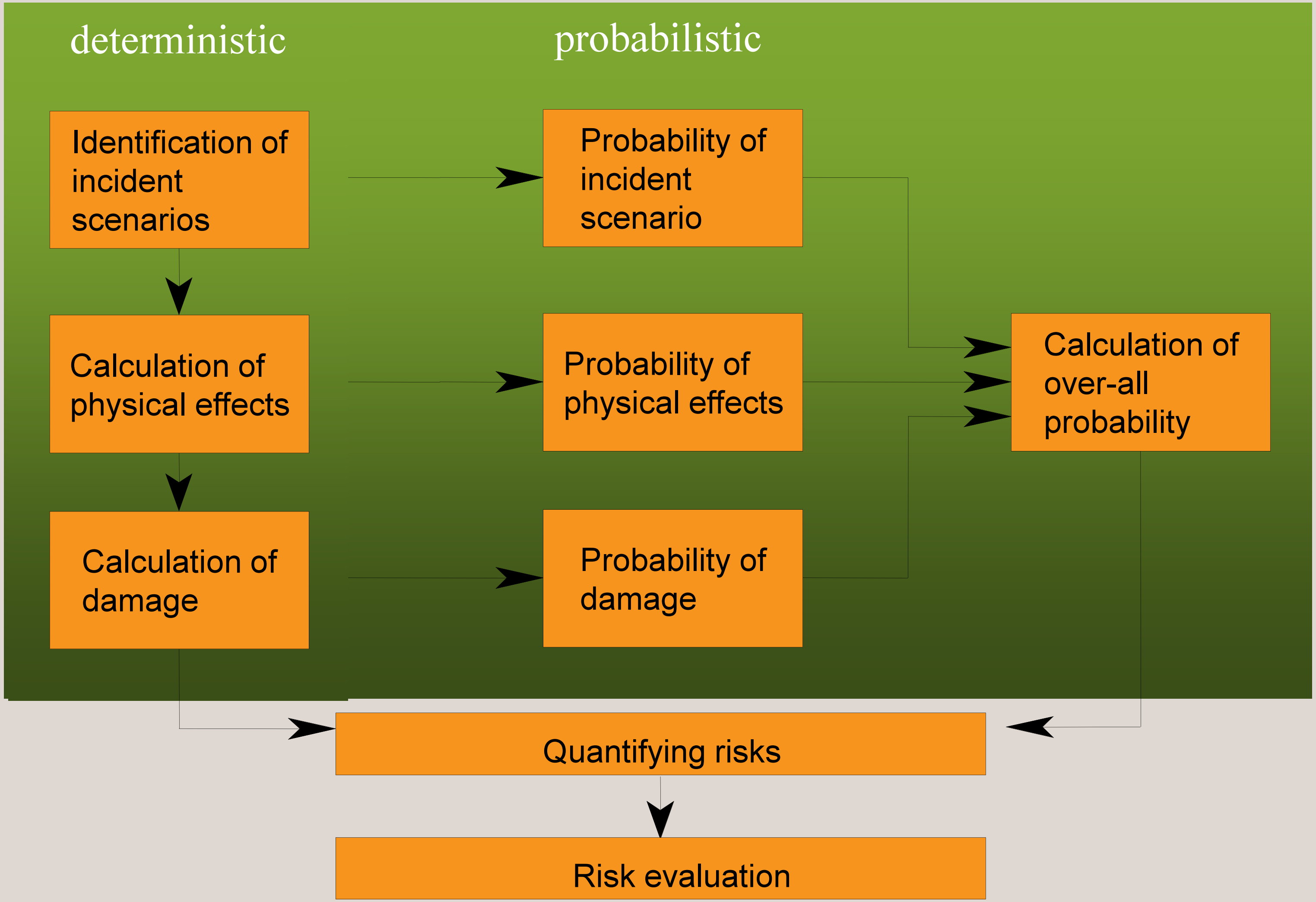


1. 1. Point initiation at the bottom of the bottom layer
2. 2. Surface initiation at the bottom layer (height of 1 big bag)
3. 3. Point initiation at the top of the middle layer

Results of the Simulation With TAN

- The simulations show that the pressure at the acceptor is not a monotonously decreasing function of the distance but shows some fluctuations
- The fluctuations are mainly caused by reflections of the blast wave from the ground
- The pressure at the lower layer is mainly the result of the regular blast from the donor and have a long duration.
- The comparable pressure levels at the upper layers are slightly lower (due to the larger gap) but in addition the upper layers are more prone to be hit by reflection waves from the ground.
- **These reflections result in pressure pulses of relatively larger height but of short duration**.
- **It is not clear whether the duration of these pressure pulses are long enough to initiate the top layer.**

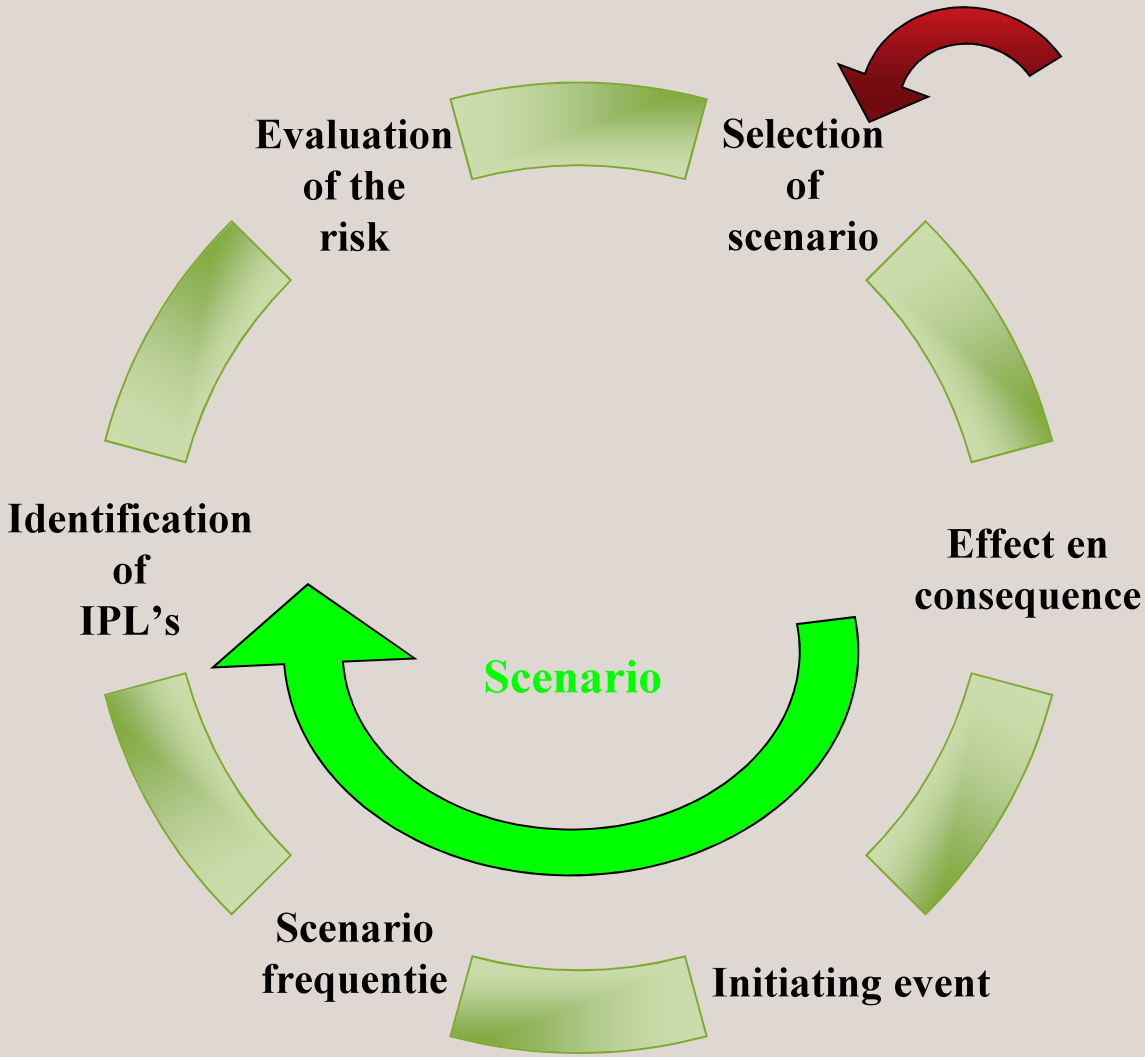
Risk analysis



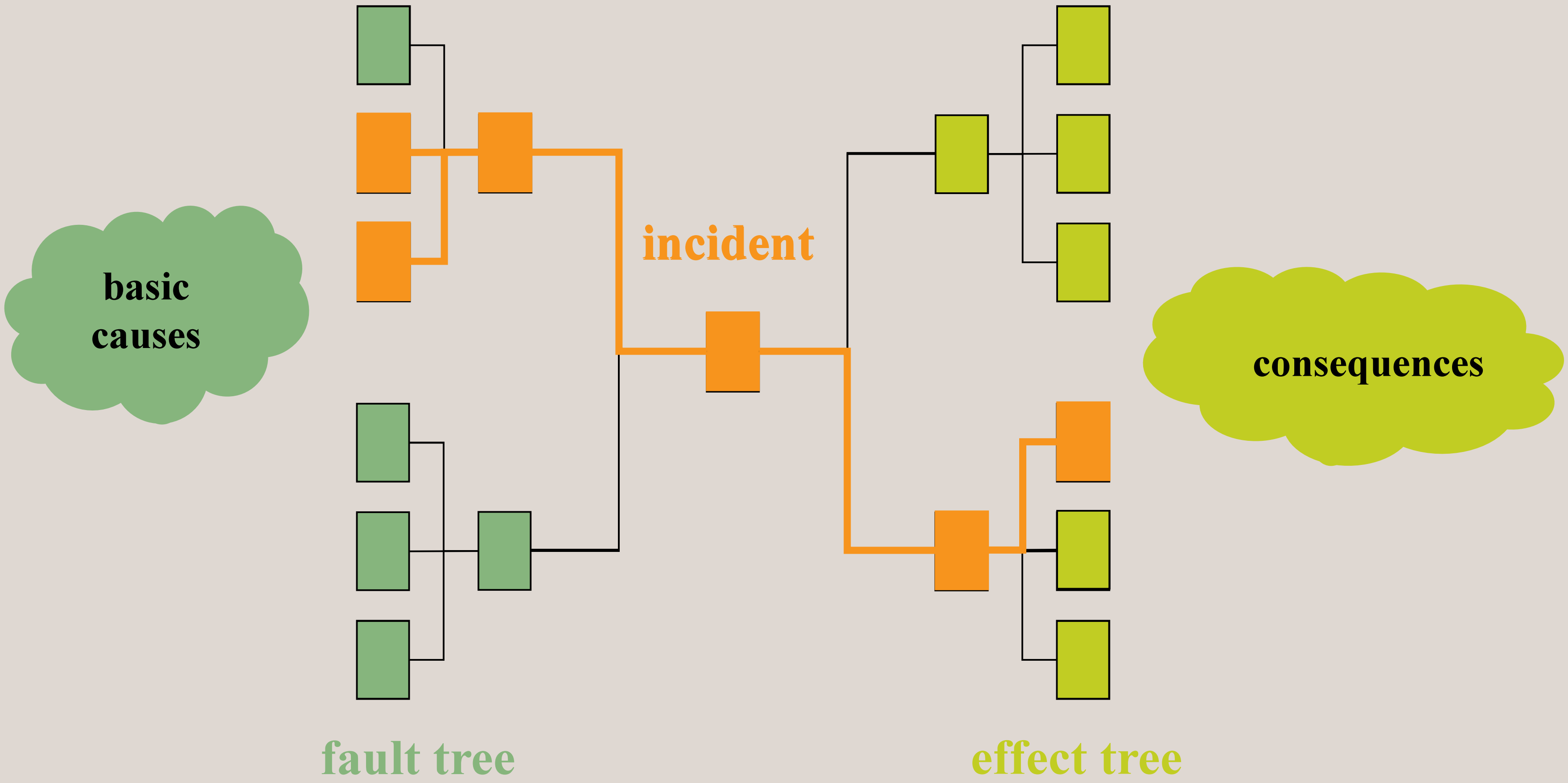
LOPA

- LOPA = Layer of Protection Analysis
- Probabilistic approach
- LOPA is a semi-quantitative risk analysis technique, between the quantitative and qualitative techniques
  - Qualitative (Hazop, check lists)
    - Identification of scenarios
    - Cannot be used for complex scenarios
    - Cannot be used for the assessment of the risks
  - Quantitative (Fault and effect tree, QRA)
    - Cannot be used for the identification of scenarios
    - Very intensive, cannot be used for a 'simple' analysis
- LOPA uses relative simple mathematics (order of magnitude)
- The most important points in the LOPA method are:
  - Identification of a scenario (cause-consequence)
  - Use of Independent Protection Layers (IPL)

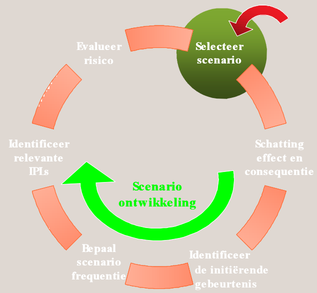
LOPA Methodology



Scenarios

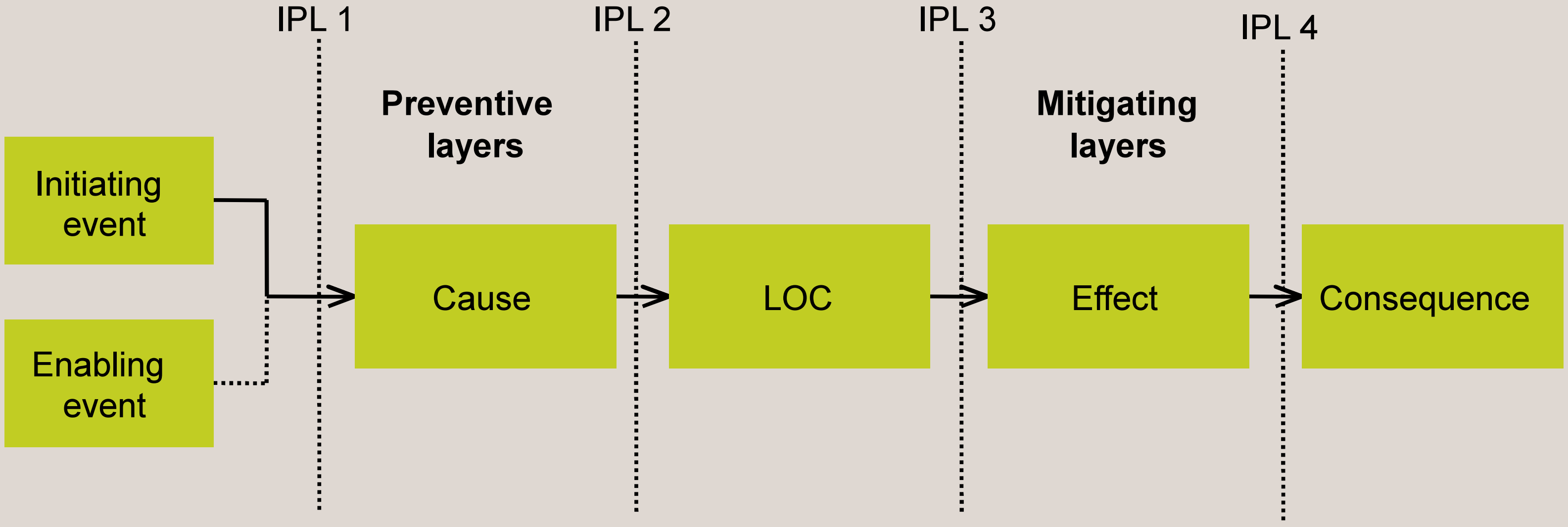


basic causes
incident
consequences
fault tree
effect tree

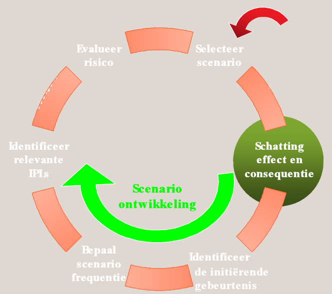


Single scenario

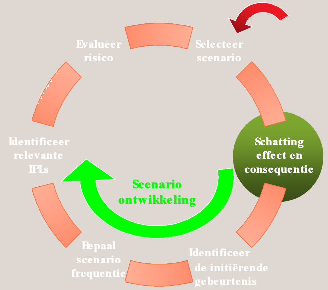
- A scenario is 1 single cause-consequence chain
- Protection layers (IPL's) are used to affect the frequencies or the effects



Consequences



Consequence class	Plant personal	Community	Environment	Financial loss (kEUR)	Material values
1 (safe)	No lost time	No hazard	No notification	< 50 *(<10)*	Insignificant damage, insignificant emissions of water, air, nitrogen, steam etc. No quality or production loss
2 (some danger)	Single injury	Odour/noise	Permit violation	50 – 100 *(10 – 100)*	Minor damage to equipment, limited extent, emissions of toxix gasses, liquid metals etc. Small quality or production loss
3 (dangerous)	>1 injury	Injuries, local news	Serious impact	10 - 100	Considerable damage to equipment, tank rupture, main equipment breakdown, etc. Considerable quality or production loss.
4 (critical)	1 – 2 fatalities	Serious injuries, regional news	Severe effects	1000 – 10,000	Major damage to equipment, breakdown of main process equipment like reactors, crackers, pipeline etc. Major quality or production loss
5 (catastrophic)	Multiple fatalities	Fatalities, International news	Disastrous effect, long term	> 10,000	Major plan damage, completely demolition of plant. Production cessation
6 (unacceptable)	Deterministic category, rupture of ammonia storage tank				



Risk matrix

Frequency of consequence (/jr)	Consequence class					
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
$10^{0} – 10^{-1}$						
$10^{-1} – 10^{-2}$				Not acceptable		
$10^{-2} – 10^{-3}$						
$10^{-3} – 10^{-4}$						
$10^{-4} – 10^{-5}$						
$10^{-5} – 10^{-6}$		Acceptable				
$10^{-6} – 10^{-7}$						

Assumptions: Consequences

LOC	Maximum Consequence class	LTF
Small fire	1	10^{-1}
Big fire	3	10^{-4}
Decomposition	3	10^{-4}
Fire to explosion	5	10^{-6}
Explosion	5	10^{-6}
Detonation	5	10^{-6}

Assumptions; Initiating events

Initiating event	Description	Frequency [/yr]
Fire	Without contaminant, electrical cabinets outside storage, no handling, no loaders left in storage	10^{-4}/yr
Fire	With contaminant, electricity or handling etc.	10^{-3}/yr
Detonation	Off-spec or uncontrolled material; contaminations (e.g. pallets)	10^{-4}/yr
Detonation	T-AN	10^{-5}/yr
Detonation	Fertiliser grade	10^{-6}/yr
Terrorism		Not developed

- TAN and Fertilizer grade AN: It can always be discussed how big the difference between these products are, but the impact on the calculated safety gap is not very significant. This is one of the advantages of the LOPA method.
- This approximation of event frequency may not be applicable to other risk assessment methodologies

Yara Köping


Harbour
Ammonia storage
TAN-2 plant
TAN-1 plant
Nitric acid plants
N-chemical operations

LOPA YARA KÖPING Site

- Method used for dry part of TAN Plant, Intermediate silo storage and bag storages
- Outcome:
  - List of 30 actions needed to close LOPA Safety Gaps ranging from small (lid over a waste bin) to large (sprinkler system in process plant)
  - Moving of most of storages for finished product

Stack size in induvidual stroages

- M13 – 190 tons
- M17 – 190 tons
- M18 – 125 tons
- M15 – 180 tons
- M11 – 150 tons
- *V900 – 280 tons*
- *V902 – 246 tons*
- M3 – 797 tons
- M9 – 621 tons
- M14 – 364 tons
- M20 – 818 tons
- M21 – 908 tons
- *V950 – 233 tons*
- *V951 – 197 tons*

BB Storage; new layout

Köping Site

The effect of debris on the surroundings

- The aim of the simulations was to evaluate the safety levels outside the limits of the site (especially on the inhabited area) after an accidental explosion of the storage facilities.
  - Determination of debris effects for an accidental explosion of the existing storage facilities (buildings M1 and M2).
  - Determination of debris effects for an accidental explosion of the planned off-spec bin outside M2
- The safety level is defined as function of the IBD (Inhabited Building Distance [NATO]).
- The IBD is accepted as an international regulation. It is defined as the distance above which the debris density is smaller than 1/56 m2 and the impact energy of debris is smaller then 79 J.
- This corresponds to a 1% hit probability of lethal debris.

The effect of debris on the surroundings

- The outcome of the simulations showed that accidental explosion of one of the silos inside building M2 represents a safe scenario for the village due to the ratio 'amount of TAN to the volume of the building'. Debris density and impact energy is below the NATO criteria. No further modifications are required.
- Accidental explosion of new off-spec storage represents a threat to the village independent of the type of walls.
  - Shielding from surrounding buildings reduces the lethal probability considerably in the major area of the village, although in 10% of the village the lethal probability exceeds the NATO criterion.
  - The primary factor influencing this threat was identified as the open space between two of the buildings.
  - To reduce the threat below the defined NATO criterion, it is proposed to construct a mound next to the wall of the off-spec storage facing the village.

Conclusions

- Based on test results and available data it is found that an overall TNT equivalence of about 20 % appears appropriate for practical situations.
- With this value for the TNT equivalence the maximum allowable amount of TAN in one pile or stack can be determined, based on the maximum allowable overpressures in the surroundings (e.g. storage tanks, road).
- Contrary to dense, fertilizer grade AN, the critical separation distance for TAN depends on configuration of stacks, way of initiation and density and type of material.
- With traditional stack shapes the critical separation distances for the TAN grades tested were found to be from 9 m to 16 m
- By altering stack shape the critical separation distances were reduced to 7-9m for the TAN samples tested.

Conclusions

- By using these results and the LOPA method for risk assessment we had to move and/or redesign all of our storages and install new “safety features” (smoke detectors, flame retardant belts, sprinkler systems, barriers etc.)
- Max stack quantity determined by using TNT equivalence of 0.20 and identification of distances to ammonia tanks, residential areas, public roads.
- Stack separation distances based on test results (7-9 m) with revised stack lay-out.
- Debris calculations showed that new off-spec bin had to be constructed with mound on the side facing nearby village

Acknowledgement

- Thanks to:
  - TNO
  - FOI
  - Yara Köping