

Safety Challenges in mobile explosives manufacturing from an engineering perspective

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Who is Bent Aanonsen?

- Age 68, now retired.
- Mechanical engineer / Business economist
- 28 years in Dyno Nobel and Orica as;
 - Maintenance manager
 - Mechanical design and development manager
 - Speciality: Development of mobile production equipment
 - Responsible engineer / auditor.
 - Member of Dyno Nobel and Orica global expert teams for explosives equipment.

Mobile equipment design and development in Scandinavia

The majority of the mobile production equipment used in the Nordic countries has been developed and designed in-house by the explosives manufacturers.

Various outside companies in Scandinavia have been used for manufacturing of the hardware, while mechanical design and development of control systems and responsibility for compliance to regulations has been done in-house.

A significant difference from other countries has been the regulation about ANE tanks in Aluminium. This has made it difficult to import “turn-key” equipment from countries outside Scandinavia.

Rules and regulations

- European regulations
 - ADR
 - SEVESO III
 - EC directives, Machine, Low voltage, EMC, Pressure vessels etc.
- National regulations
 - National explosives regulations
 - National transport regulations
- Internal company rules
 - Basis of safety standards
 - Critical machine standards
 - Engineering standards
 - Safety, health and environment Model procedures
 - Management of changes
 - Training programs.

The CE Machinery Directive

Principles of safety integration

- (a) Machinery must be designed and constructed so that it is fitted for its function, and can be operated, adjusted and maintained without putting persons at risk when these operations are carried out under the conditions foreseen but also taking into account any reasonably foreseeable misuse thereof.
- The aim of measures taken must be to eliminate any risk throughout the foreseeable lifetime of the machinery including the phases of transport, assembly, dismantling, disabling and scrapping.

Machinery Directive, Annex I

- *1.5.7. Explosion*
- *Machinery must be designed and constructed in such a way as to avoid any risk of explosion posed by the machinery itself or by gases, liquids, dust, vapours or other substances produced or used by the machinery.*
- *Machinery must comply, as far as the risk of explosion due to its use in a potentially explosive atmosphere is concerned, with the provisions of the specific Community Directives.*

Critical issues, critical machines

Fuel and oxygen is always present in Ammonium Nitrate Emulsion (ANE) and finished products.

- ANE will decompose between 140°C and 170 ° C.
- ANE will burn violently.
- ANE will explode if confined while burning.
- Other substances like ANPP, Fuel oil, Aluminium, Expancells etc. are adding risks on a compact mobile production unit.

Critical issues, critical machines

- What is needed to start a fire or detonation is a source of ignition with sufficient energy.
- Any place where energy is introduced into the process is a potential ignition point.
- On a mobile production unit, such critical points are pumps, mixers, augers, and heating systems.
- Historically, **the most critical process components are the pumps.**
- A pump running with no flow will generate heat. The heat will accumulate and the temperature will increase depending on type of pump, speed, inside friction and possible heat transfer to the environment.
- Pumps and High shear mixers in the process line are often defined as **CRITICAL MACHINES.**

Comparison of pump applications; Where is the highest risk?

Production pumping

1. Production stops between boreholes.
2. The operator will immediately discover flow interruption.
3. Unlikely to reach critical temperature in pumps or mixers before interrupted flow is noticed.
4. The operator can not leave the job during production.
5. Sophisticated instrumentation is necessary to ensure product quality. Not possible to use the MPU with defective control systems.
6. Production sites usually possible to evacuate in case of fire.

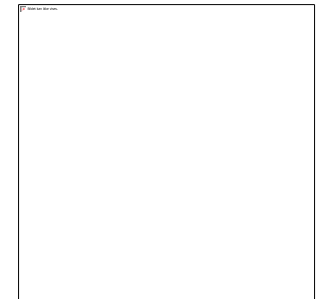
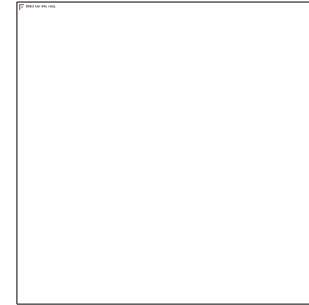
Transfer pumping

1. Continuous pumping between tanks.
2. The operator does not see flow directly.
3. Pumping cycle time is long enough to reach critical temperature if the pump is running with no flow.
4. The operator is able to leave the job.
5. The pump can operate with a defective shut down system.
6. Transfer pumping usually goes on at more populated sites where evacuation in case of fire is more difficult.

What does “reasonably foreseeable misuse” mean?

Some examples:

- Deliberate violation of rules.
 - Neglecting to ensure flow through running pumps....
 - Extending inspection intervals.
 - Illegal experimenting.
 - Illegal hot work
- Unconscious violation of rules.
 - «Helping» colleagues without knowing the rules.
 - Misunderstanding, language problems etc. Human error
 - Human error
- Use of equipment for applications which it was not designed for.
 - Wrong type of pump for transferring ANE.



1.2.4.4. Assembly of machinery

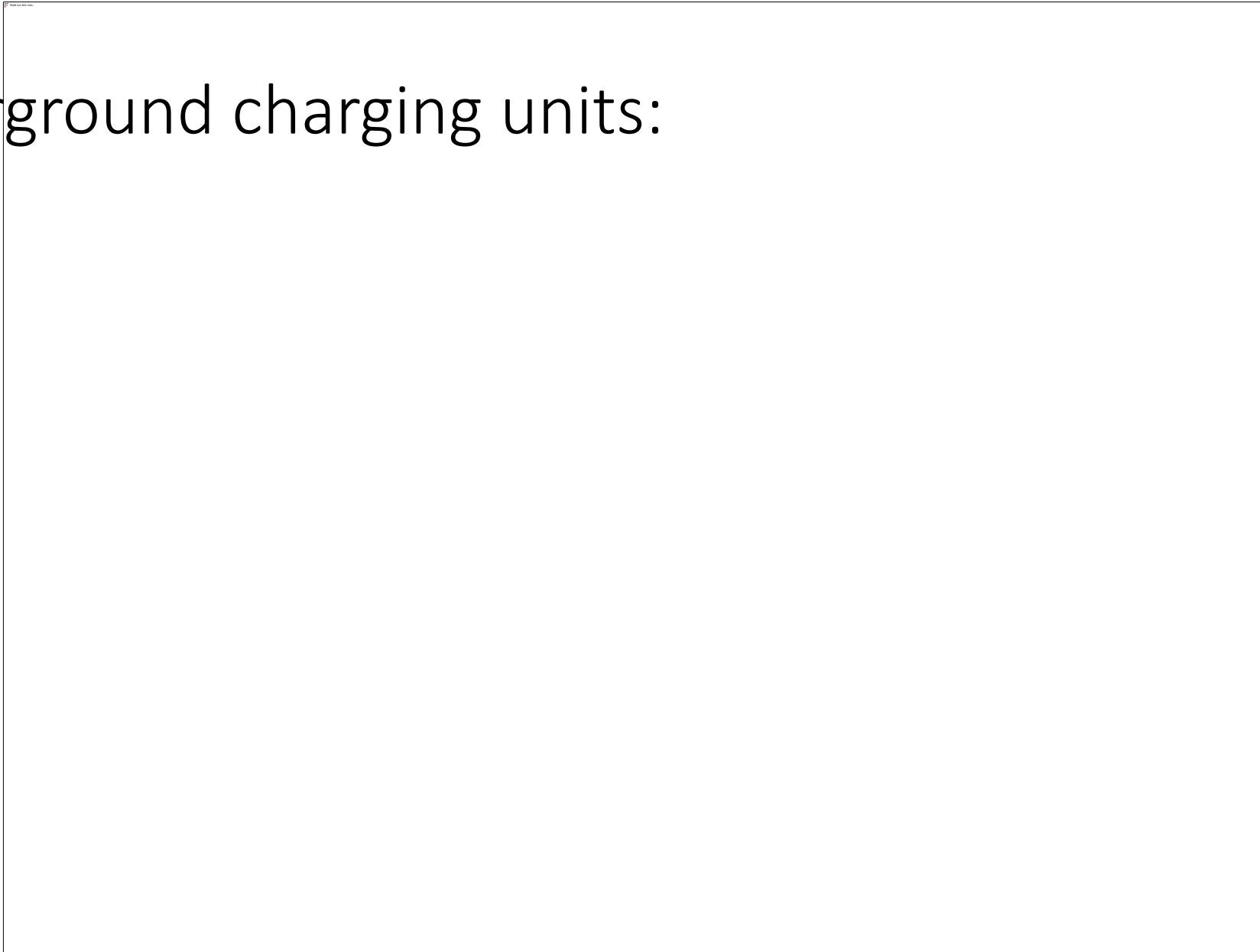
*In the case of machinery or parts of machinery designed to work together, the machinery must be designed and constructed in such a way that the stop controls, including the emergency stop devices, can stop **not only the machinery itself but also all related equipment, if its continued operation may be dangerous.***

- The manufacturer of such assembled machinery must comply to all the same requirements as a normal machine manufacturer has, including a review of the original risk assessment and completing a new certificate of compliance.
- Usually it is the explosives manufacturer who have to take the role as “manufacturer” of the machine assembly. In particular related to mobile explosives production of temporary character, such as construction sites, where different equipment is used together in a system and the components has not previously been used together. The explosives manufacturer has the responsibility for the new system being in compliance with the Machine Directive.

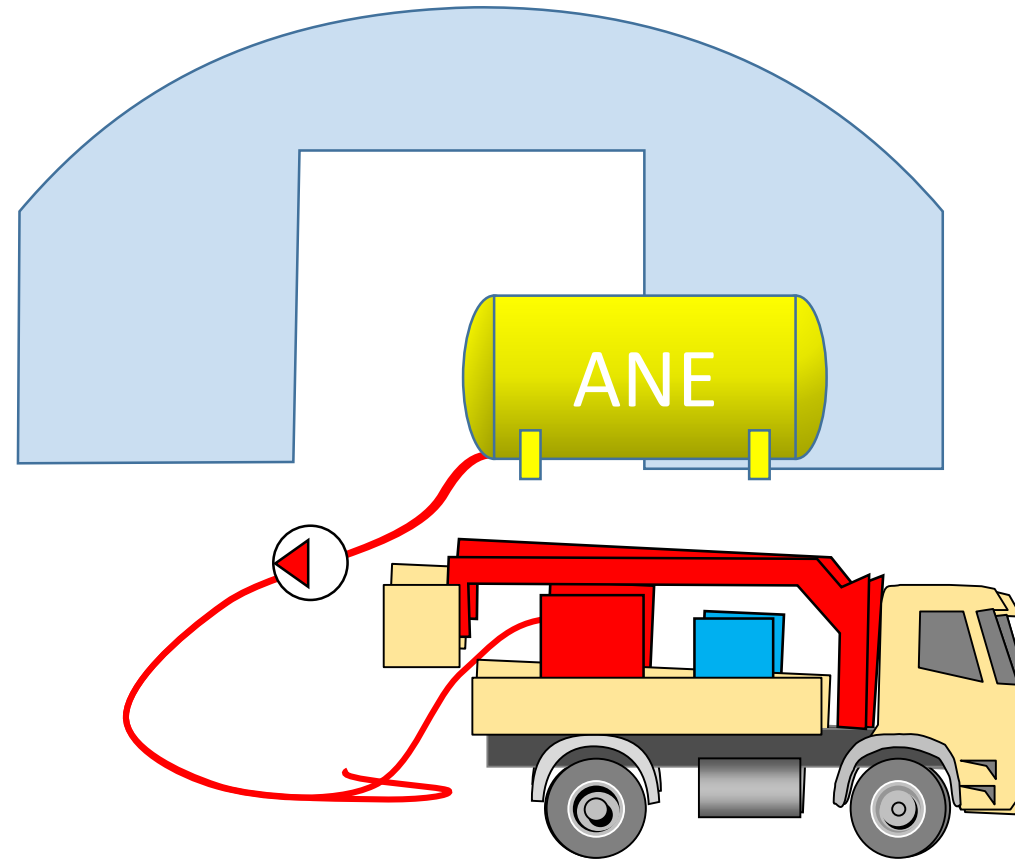
Transfer pump example:



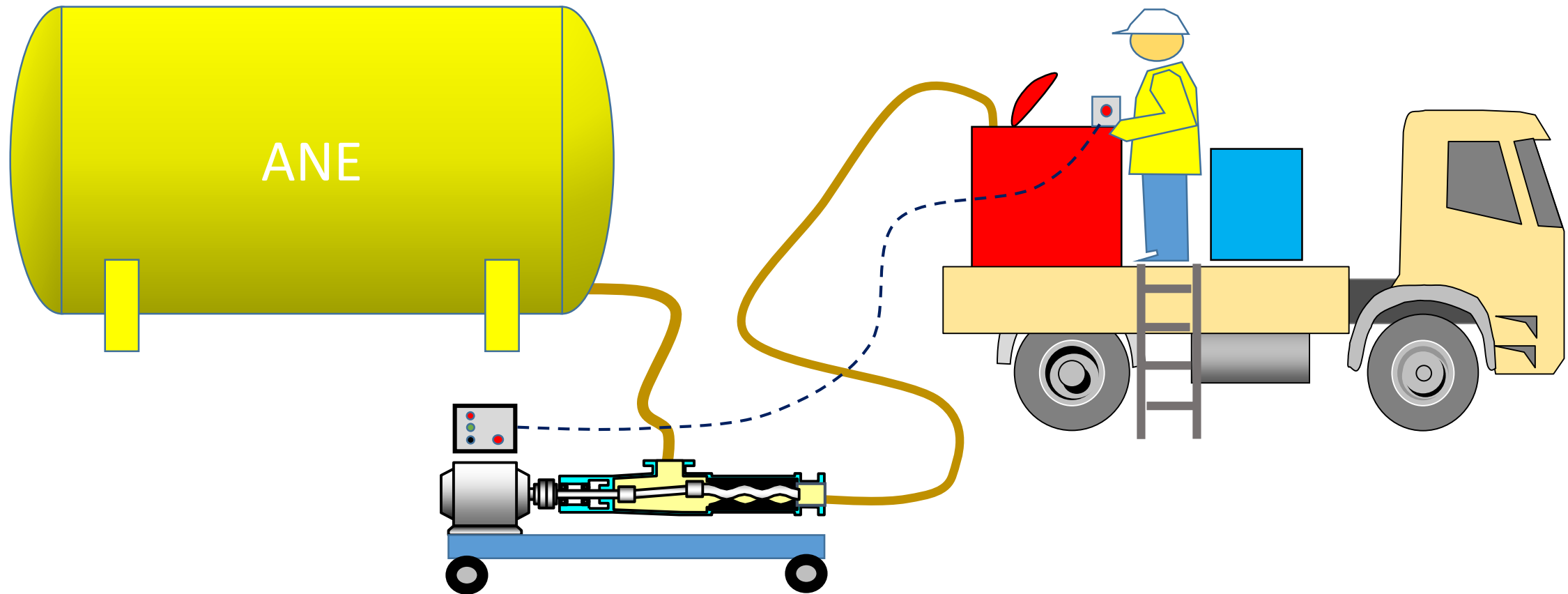
Underground charging units:



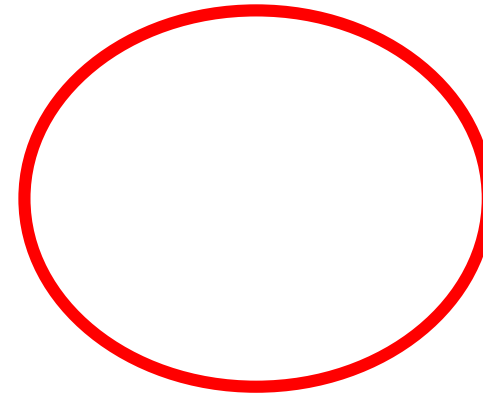
Transfer of ANE from depot tank to charging unit



ANE tank filling: The operator has a stop button connected to the transfer pump. He can see the level in the tank and stop the pump when the tank is full.



MANUAL MONITORING OF THE
LEVEL IN THE ANE TANK WHILE
FILLING THE TANK



Assembly of machines 1.2.4.4

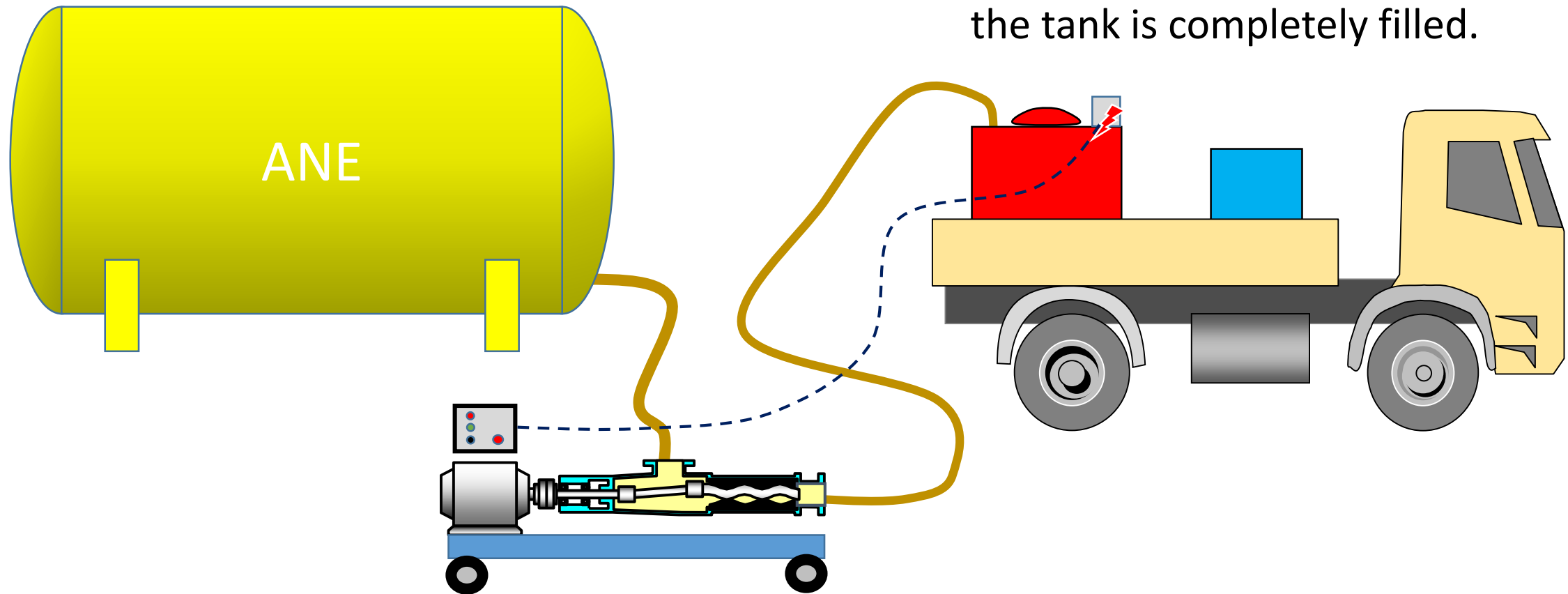
The CE marked, complete system consist of:

- 1) A suction hose between ANE storage tank and transfer pump
- 2) A transfer pump with electric motor and cabinet with control system and critical trips.
- 3) An ANE storage tank
- 4) A delivery hose between transfer pump and ANE tank on the MPU
- 5) A connection cable between transfer pump's control cabinet and the circuit breaker on the MPU's ANE tank.

IF ANYTHING IS CHANGED, THE CE MARKING IS NOT VALID ANYMORE.

Operations want a change:
The operator should not need to climb the ladder and risk injury by falling.

A level sensor is now stopping the pump automatically when the tank is completely filled.



What has changed?

- The operator does not need to monitor the rising level in the tank.
- The operator does not see the flow or changing levels.
- The operator has opportunity to leave the pump running (even if the company rules forbid it).

Consequence:

- the most important level of protection against dry running or dead heading is lost; **the presence of the operator**.

To maintain an acceptable level of protection, redundant safeties have to be in place!

Critical heat generation in PC pumps

1. Continue pumping after the tank is empty:



Critical heat generation in PC pumps

2. Continue pumping with a blocked inlet:



ANE transfer pump – single stage PC pump
Result of dry running; Burning started at the inlet side.



Critical heat generation in PC pumps

3. Continue pumping with clogged or blocked outlet:

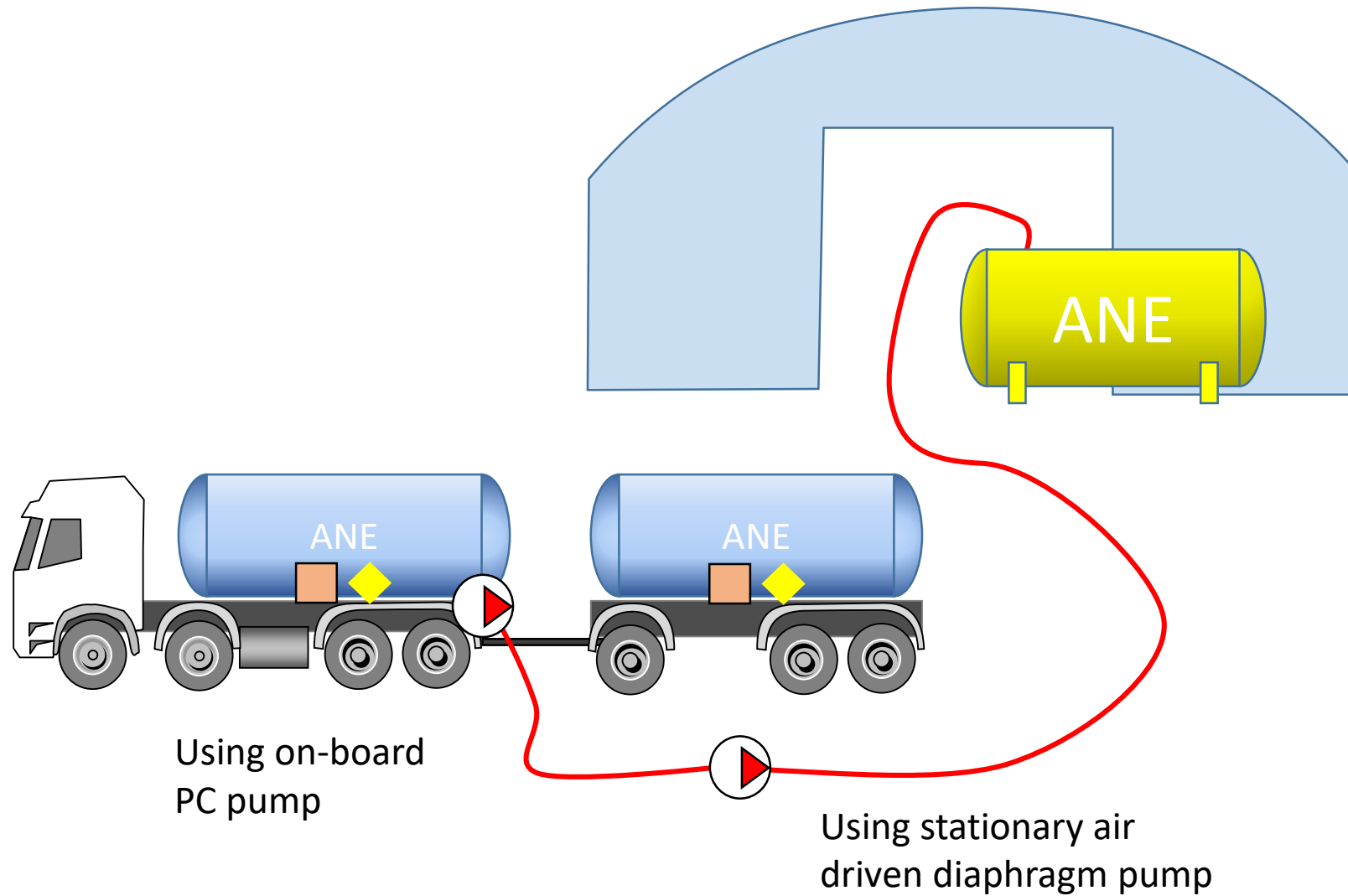


Risk Assessment of transfer pump (example)

Dangerous situations	Consequence	Estimated probability	Is the risk acceptable?
The pump is running with blocked outlet without being noticed and/or stopped by the operator.	The pump is overheated and detonates.	Once pr. Year or more often.	No
The pump is running dry with blocked inlet – The suction screen is blocked without being noticed and/or stopped by the operator.	The pump is overheated and detonates.	Twice pr. Year or more often.	No
The pump is running dry - The tank is empty, without being noticed and/or stopped by the operator.	The pump is overheated and detonates.	Once pr. Year or more often.	No

Example 2:

Transfer of ANE from ADR transport vehicle to depot tank



Management of changes and modifications, minimum requirements

- Any significant change in equipment or process must be reviewed by a competent team before it is approved.
- The competent team must represent all relevant disciplines and be formally appointed.
- The change must be described and explained and this documentation must be available for later needs.
- Technical documentation which is the basis for CE marking must be updated and a new certificate of compliance must be issued if necessary.

Engineering challenges,

What has changed during the last 30 years in the explosives industry?

Increased competition -> cost cutting

- From an engineering perspective this leads to:
 - New investments only if pay-back time is short.
 - Increasing focus on project estimates, (time and money)
 - Reduced investments in research and development.
 - Travel restrictions. Reduced global communication between colleagues.
 - Delayed or missing recruitment.
 - People who leaves are not replaced.
 - Multi tasking, roles are combined because of limited staff.
 - HSE staff focussing more on paperwork than “hands on” auditing.
 - Outsourcing of maintenance. Loss of feed back and corporate know how.
 - Loss of “Critical mass”.

Acquisitions and mergers

- Mix of different technologies and equipment.
- Centralisation of engineering functions.
- Head quarters and technology centres outside EU.
- Limited understanding of EC directives.
- Efforts to standardise of equipment to get synergies.
- Language issues and cultural differences.

Insufficient knowledge at some equipment manufacturers.

- Machine manufacturers, who are not explosives manufacturers themselves, do not always understand all risky steps in the process.
- “Combination-designs” frequently lead to more sensitised product in the process line than necessary.
- Poor dynamic stability at partial load due to high centre of gravity in tanks.
- Insufficient elasticity between truck chassis and superstructure attachment points leads to cracks in tanks when driving off road at mine and quarry sites.
- Insufficient pump safeties, solutions that are “blind” to some scenarios.
- Incomplete user manuals. The machine manufacturer is often unfamiliar with the environment of use.
- Difficult access for maintenance. The number of units in a series are often too low for successful optimising of maintenance.
- Broken feed-back loop. Lost opportunities to improve the machines.

20 years with the Machinery Directive 1.

- 1995 – We had to learn to CE-mark our equipment, even if it was only to be used in our own company and not be sold on the market.
- The demand for documentation increased significantly.
- New mandatory requirement for risk assessment for all aspects of machinery, not only risk of fire and explosion, which the explosives industry traditionally had been focussing.
- It became difficult to import equipment from countries outside the European union without the CE mark. Several previous suppliers failed to comply and gave up.

20 years with the Machinery Directive 2.

- From the beginning we expected to be audited by the national authorities. If something happened, the technical files had to be correct.
- No audit ever happened, except the demand for CE compliance statement.
- The Machinery Directive is a massive book of rules and can be interpreted in various directions. However, the Certificate of compliance must anyway be respected and give the product legal access to the market....!
- Production units on MEMUs are only inspected according to ADR rules and use on public roads and not the related to the risks in use during loading and delivery of products.
- Without inspection from the authorities, the competition will be unfair. The safest operations loses competitiveness due to higher cost.

20 years with the Machinery Directive 3.

- No mandatory inspection intervals.
- Machines are modified without updating the technical documentation.
- Machine components are combined without CE marking the complete system.
- “Reasonably foreseeable misuse” is underestimated.
- Spare parts availability is changing. Alternative parts have to be used, but these parts might have different properties and performance.
- Tasks which nobody ask for are not always carried out.

Auditors checklist for critical machine systems

1. Have all machine systems been classified as "critical" or "non-critical" according to the potential consequences from failure of the machine or its protective systems?
2. Has the design of Critical Machine Systems and any modifications to such systems been verified by a suitable design verification authority?
3. Have the hardware and software systems provided to protect Critical Machine Systems been identified and recorded? Have arrangements been identified and recorded for the periodic inspection, testing and maintenance of the hardware and software systems?
4. Were/are Critical Machine Systems inspected during the course of manufacture or modification to verify that components and assemblies comply with the design requirements?
5. Before commissioning, were installed Critical Machine Systems inspected and pre-commissioning tests completed to ensure compliance with the intended design? And recorded?
6. Are Design records and records of all inspections being kept for the life of the critical machine system?
7. Are the machines in use still as documented in the technical files?
8. Has/is information regarding Critical Machine System failures been communicated throughout the company? Were investigation reports copied to the company mechanical engineer within XXX working days of a significant failure?