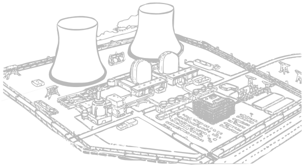

Major industrial accidents

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Learning from the "gift of failure"

Learning objectives

- These slides contain brief descriptions of a number of major industrial accidents
  - together with the lessons learned from the investigation
- Learning from experience is a major source for safety improvement
  - the "gift of failure" [B. Wilpert]
- We focus on accidents where the technical/technological contribution was significant
  - many major accidents have causal factors that are primarily organizational (not the focus of this module)

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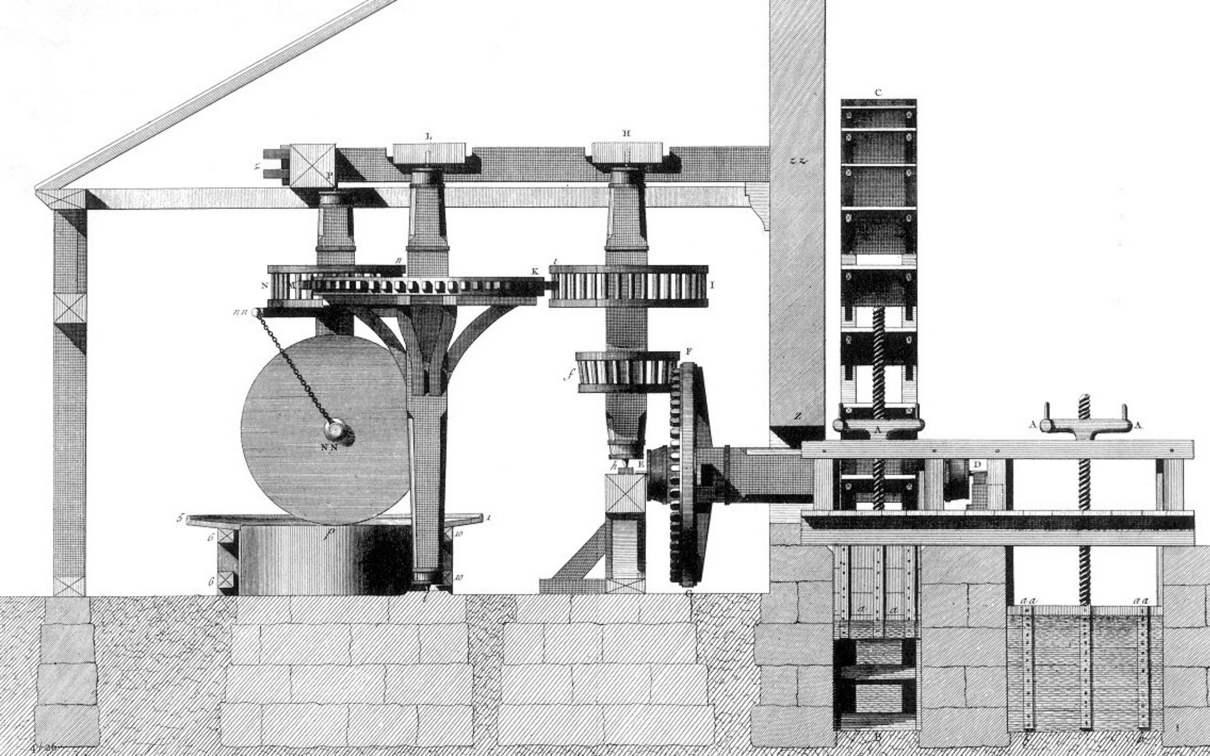
Manufacturing gunpowder

- ▷ Gunpowder ("black powder") is the oldest known explosive
  - mixture of sulfur, charcoal, and potassium nitrate (saltpeter)
  - invented in China in 9^{th} century
- ▷ Its production and storage are perhaps the first hazardous industrial activity



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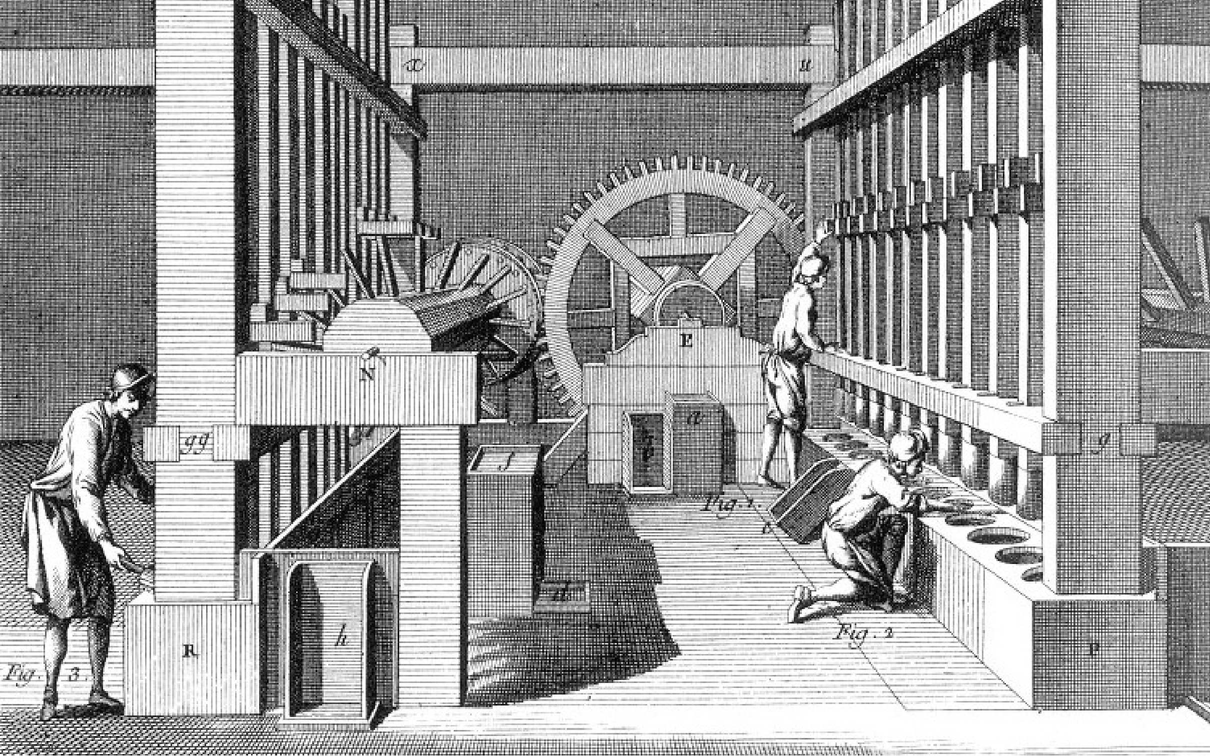
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Fig. 1.
Fig. 2
Fig. 3.

Hazardous!

A very hazardous product!

- many accidents during production, transport, storage

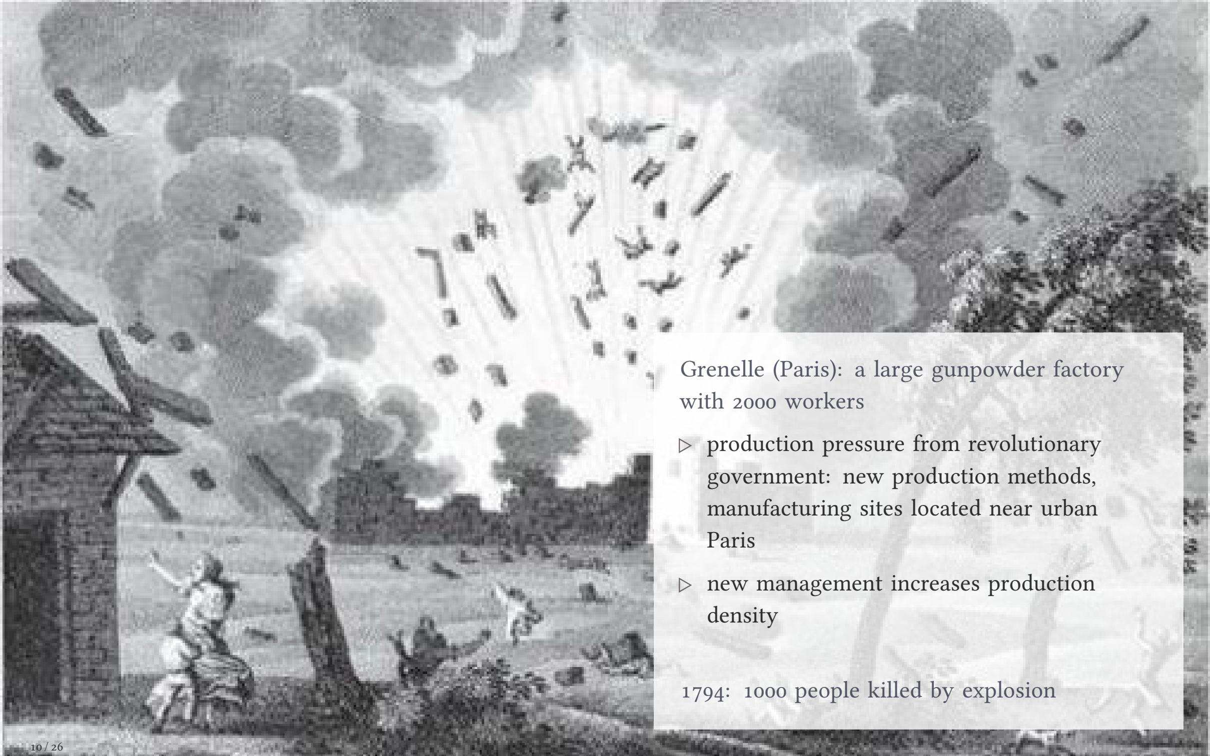
Lessons learned:

- locate production and storage far from urbanized areas
- use multiple small facilities so that fewer workers killed in each explosion

Toulouse in ~ 1680

A gunpowder factory in Toulouse

Île du Ramier, Toulouse



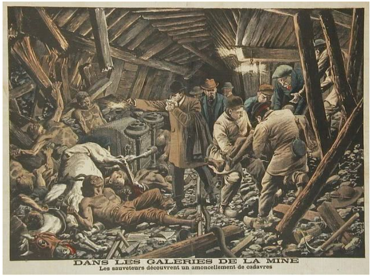
Grenelle (Paris): a large gunpowder factory with 2000 workers

- production pressure from revolutionary government: new production methods, manufacturing sites located near urban Paris
- new management increases production density

1794: 1000 people killed by explosion

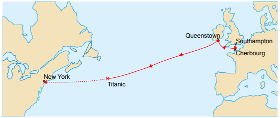
1906: Courrières mine disaster (France)

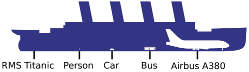
- ▷ 1099 miners killed by a **coal dust explosion**
  - worst industrial accident in French history
- ▷ Lessons learned:
  - introduction of explosion barriers
  - use of safety lamps
  - creation of specially trained emergency teams



Titanic (1912)

- British passenger liner that sank in the Atlantic after colliding with iceberg
  - largest ship in the world at the time
- More than 1500 passengers and crew killed
- Many died due to lack of sufficient lifeboats
  - and lifeboats launched before they were full (706 people saved, 1200 person capacity)





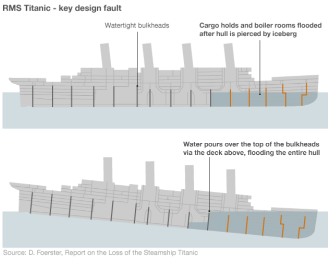
Titanic: contributing factors

▷ Designer hubris

- ship described as "practically unsinkable"
- hull with 16 "watertight" compartments with remotely controllable doors
- in fact, water could flow in via the roof of each compartment

▷ Operator hubris

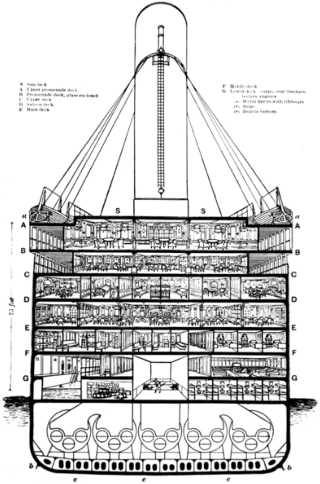
- ship did not slow down after being warned of presence of icebergs
- lifeboat capacity for only one third of ship's capacity (outdated regulations)
- inadequate training on evacuation



Hubris: excessive pride & confidence

Titanic: contributing factors

- ▷ Badly built with low quality rivets
  - iron rivets instead of steel in some sections
  - many large ships under construction simultaneously: shortage of quality rivets
  - pressure to finish the ship on time
- ▷ Inadequate regulations
  - very large ships: number of lifeboats required not a function of passenger capacity
  - no requirement to build double hull
- ▷ Poor organization of emergency response



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Titanic: lessons (re)learned

- Defence in depth
  - prevention does not eliminate the need for mitigation
- Regulations must be updated to follow technological progress
- Improved emergency communication
  - creation of International Convention for the Safety of Life at Sea (SOLAS)
  - 24-hour radio watch on ships, secondary power supply for radios
- Addition of double hulls
  - Titanic had a double bottom but no side protection (heavy, expensive)

BLEVE at Feyzin (1966)

- ▷ Operator was sampling from a pressurized propane sphere (quality control)
- ▷ Mistake in order of valve opening leads to frozen valve and propane leak
- ▷ Car passing on nearby road ignited cloud
- ▷ Leak from sampling line ignited
- ▷ BLEVE of the tank
- ▷ Domino effect to other nearby spheres and oil tanks

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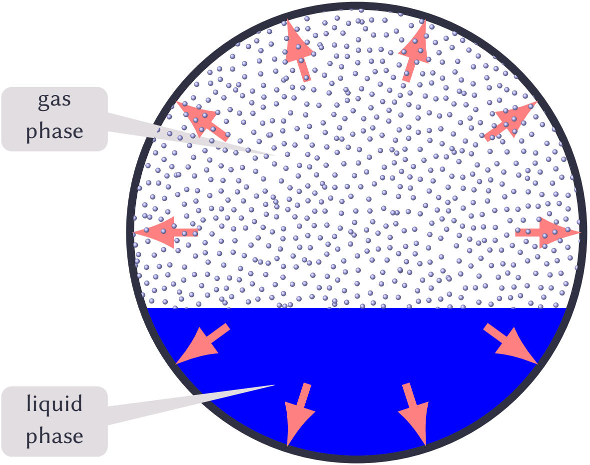
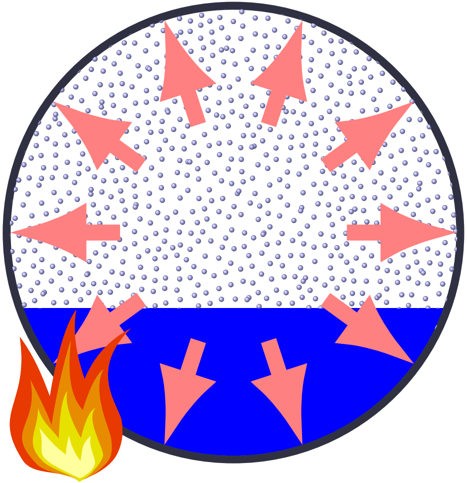


Fuels such as butane and propane are generally stored as pressurized liquids at a temperature higher than their boiling point.

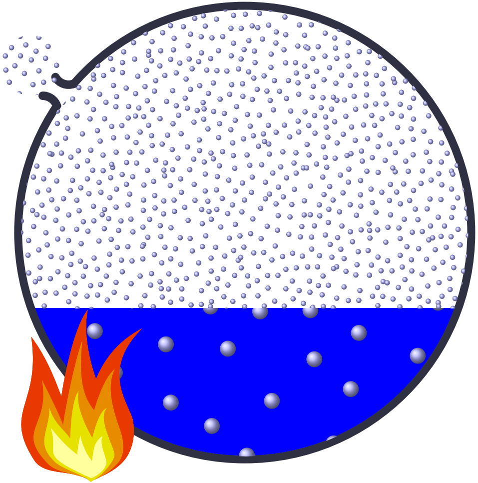
Typical pressures: 17 bar (1700 kPa).



An initial event (often a jet fire) leads to **heat impinging on the storage vessel**.

Pressure inside the tank increases.

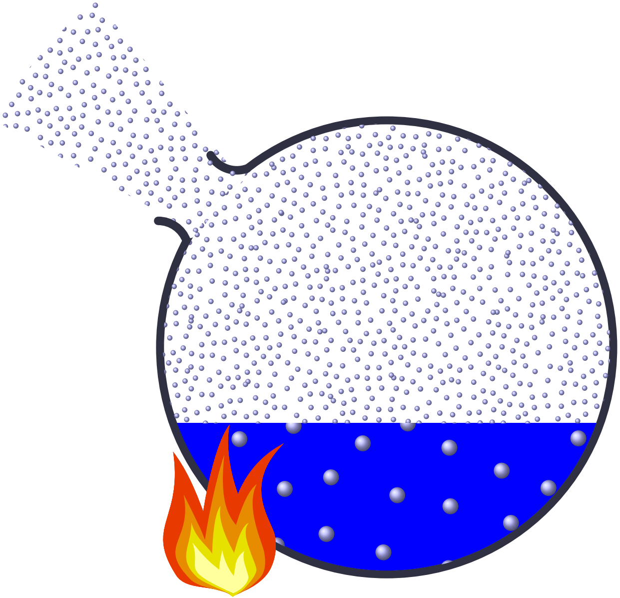
The liquid in the tank cools down the metal in the lower part of the vessel, but the upper part of the tank may become weaker due to heat.



The vessel fails, initially with only a small hole.

Gas **leaks** from the hole, rapidly lowering the pressure inside the tank.

The liquefied gas **boils** violently (its boiling point is pressure-dependent).



BLEVE: Boiling Liquid Expanding Vapour Explosion

The boiling liquid **vapourizes**, increasing pressure in the vessel and ripping it open. A huge volume of gas is ejected into the atmosphere.

Massive **blast**. If material is flammable, a huge **fireball** forms with massive heat radiation.

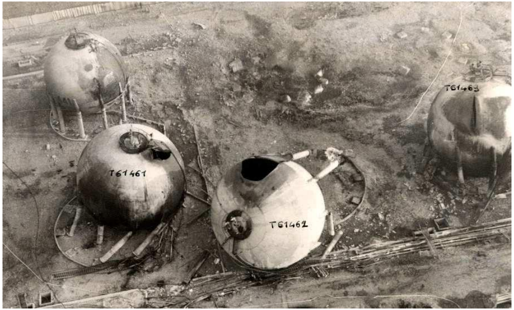
BLEVE after train derailment in Casselton, North Dakota (2013)

BLEVE: explanatory video

Explanatory video: `youtu.be/UM0jtD_OWLU`

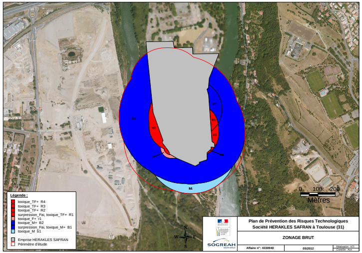
Feyzin: BLEVE effects

- ▷ 18 people killed, extensive damage
- ▷ 48 hours to put out blaze
- ▷ Missiles ejected 700 m away
- ▷ One 48 tonne element ejected 325 m



BLEVE at Feyzin: lessons

- ▷ Protect tanks from impinging heat
  - insulation, sprinklers
- ▷ Site layout to avoid domino effects
- ▷ Protect firefighters
- ▷ Manage urbanization around high-hazard industrial sites



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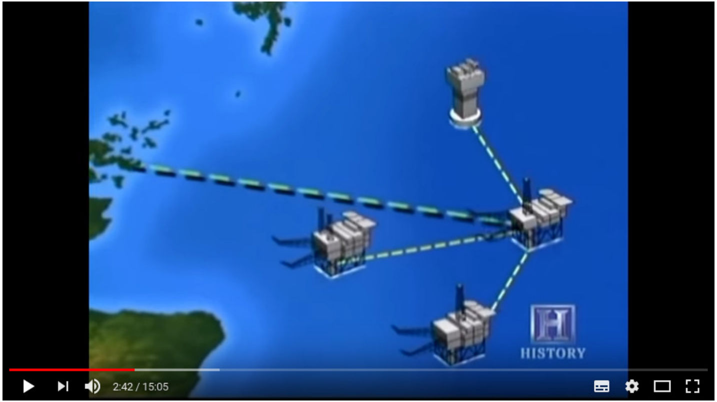
Piper Alpha



Watch the video: `youtu.be/tPA_6oEgc1s`

Explosion at Caribbean Petroleum, Puerto Rico

US CSB safety video *Filling blind*, 2015

Watch the video: `youtu.be/41QMaJqxqIo`

Lac Mégantic derailment

Canadian TSB animation on the 2013 derailment and fire

Watch the video: `youtu.be/wVMNspPc8Zc`

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