



Overview

- The Events
- The Explosions
- The Sequence
- Bow Ties
- External influences
- Underlying Causes
- Lessons –

Phenomenology and Institutional

The Event

- June 1st 1974, a major explosion and fire destroyed the Nypro Plant at Flixborough.
- On site 28 were killed and 36 injured.
- Offsite, 53 casualties, ~2000 houses, ~200 shops and factories damaged- £100 million bill)
- Court of Inquiry, Factory Inspectorate conflicted, Cremer and Warner led Investigation for the Court.
- Led directly to the development and application of Risk Analysis as a formal procedure for Major Hazard Installations (by Dutch and Norwegians)

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The NYPRO Plant

- Totally destroyed on June 1st 1974

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SITED PLAN OF
ROUGH WORKS
10 INK/1.0

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The Process

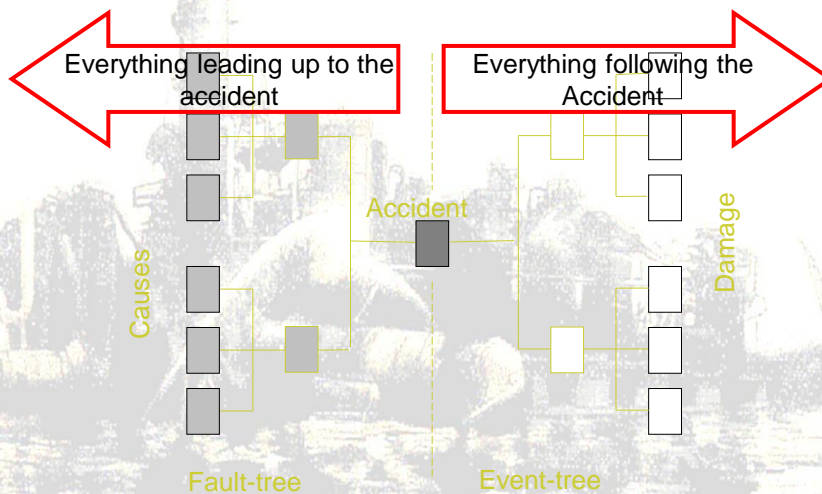
- Dutch State Mines and the Coal Board built a Nylon 66 Plant on the site of an old fertiliser complex at Flixborough.
- Designed and built by Simon Carves.
- Conventional low temperature, liquid, catalytic oxidation of cyclohexane to cyclohexanone, which was further processed to caprolactam, the Nylon 66 monomer.
- Relatively inefficient conversion meant a continuous circulation of some 200 tons of C6 thro' 6 cascade reactors of ~25 tons in a stepped sequential arrangement

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Bowtie



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Time Line 1

- March 27th – Cracks discovered in the mild steel casing of Reactor 5.
- Construction of mild steel outer with bonded stainless steel inner meant integrity was possibly impaired and reactor lifted out of the line.
- A temporary connection (dog legged to allow for step change) was fabricated to enable the circulation to continue.
- Tested cold to process, but not relief valve pressure.
- April 1st, plant restarted normally and dog leg subsequently lagged.
- Mid May Plant Inspected

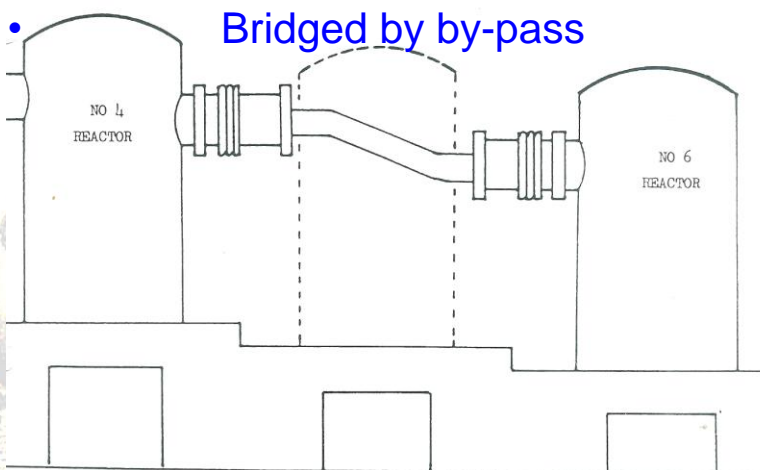


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Missing Reactor



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Time Line 2

- May 29th – more leaks caused the plant to be shut down for repair and maintenance.
- Preparations for restart over coming weekend modified as there is insufficient Nitrogen supplies to use as inerting medium. Water alternative adopted, not unusual.
- June 1st – Plant loop now charged with C6 being warmed up to process Temperature(160 C) and pressure (120 psi).

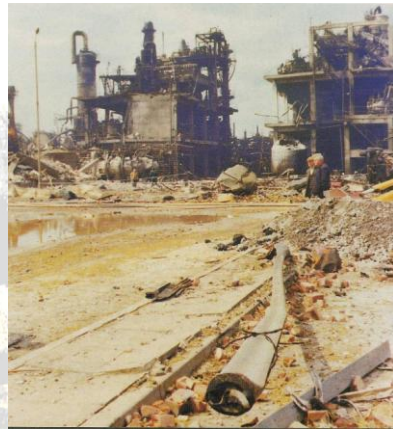
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The Event

- Consequences –
Site wide Fire many days duration
Excavation of debris to recover casualties
Factory Inspectorate not formally involved
(post Aberfan,Robens,etc)
Unsecured site briefly, expert free access, contaminated?
Dog leg connection found ruptured
Widespread evidence of low overpressure as well as fire damage.



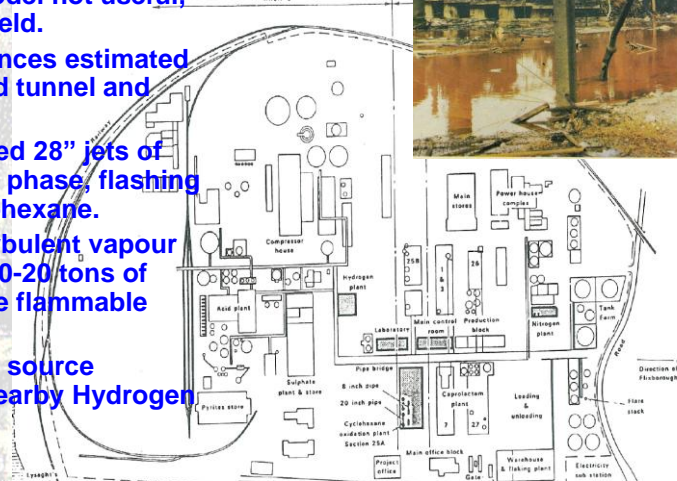
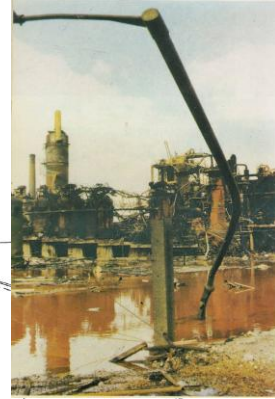
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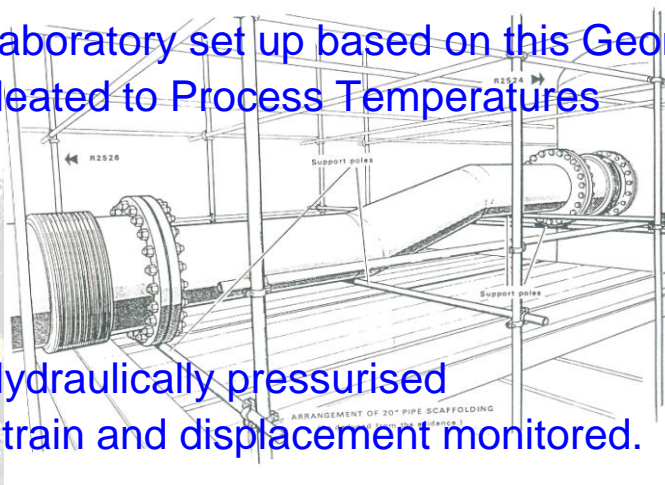
Explosion(s)

- Major overpressure event recorded by glider altimeter, ionospheric layer monitoring, surrounding property damage, smashed windows etc.
- TNT equivalent model not useful, particularly near field.
- Dog leg consequences estimated by simulation (wind tunnel and modelling).
- Two offset, opposed 28" jets of some 200tons of 2 phase, flashing superheated cyclohexane.
- Predicts highly turbulent vapour cloud with some 10-20 tons of hydrocarbon in the flammable range.
- A credible ignition source identified as the nearby Hydrogen Reformer.



Reconstruction

- Laboratory set up based on this Geometry
- Heated to Process Temperatures



- Hydraulically pressurised
- Strain and displacement monitored.

The Failure

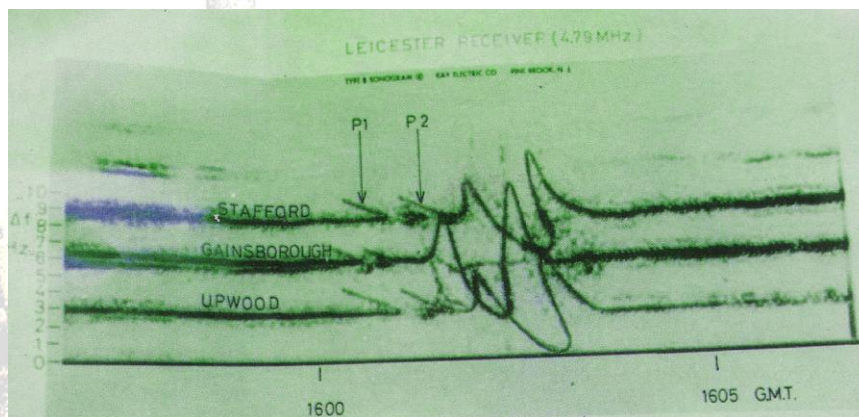
- The temporary dogleg by-pass was reconstructed in laboratory conditions, instrumented and tested to destruction; using water for safety considerations.
- At process parameters it was borderline stable/unstable.
- A small increase in pressure caused explosive geometric change and hydraulic failure (Squirming)
- Full of superheated fluid, a rupturing bellows would have caused an explosive release of PV energy. (Explosion 2)
- Identified in both glider and scattering records

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Ionospheric Disturbances



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Causes

- Explosion 1/Fire destroyed control room logs
- Previous start up logs using water inerting show significant sharp pressure surges on approaching start up conditions.
- As immiscible liquids, water could form pools in the bottom of the lager process vessels.
- On bump boiling, these would cause the overpressure events seen in the historical logs.
- (cf “aged” LNG, BLEVES etc.)
- Excess Enthalpy Explosion 3
- -always assumed in the investigation, not emphasised in the report as the court felt the instability was such as actual initiation was speculative and inevitable.

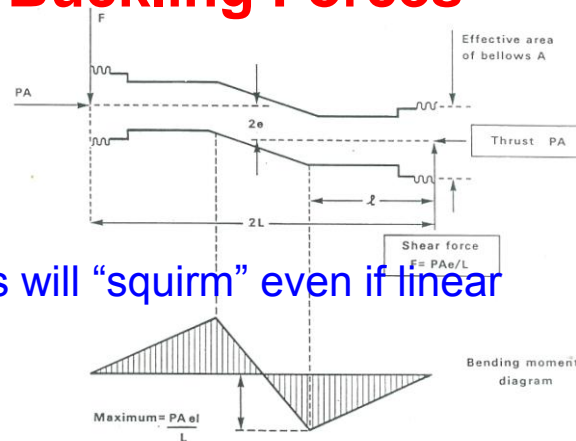
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Buckling Forces

- Bellows will “squirm” even if linear

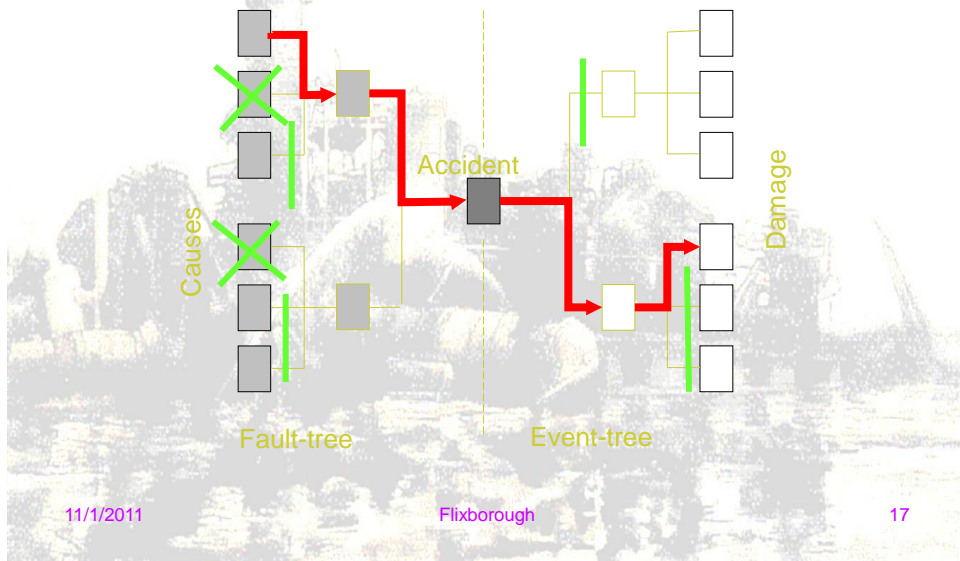


SKETCH OF PIPE AND BELLOWS ASSEMBLY SHOWING SHEAR FORCES ON BELLOWS AND BENDING MOMENTS IN PIPE (DUE TO INTERNAL PRESSURE ONLY)

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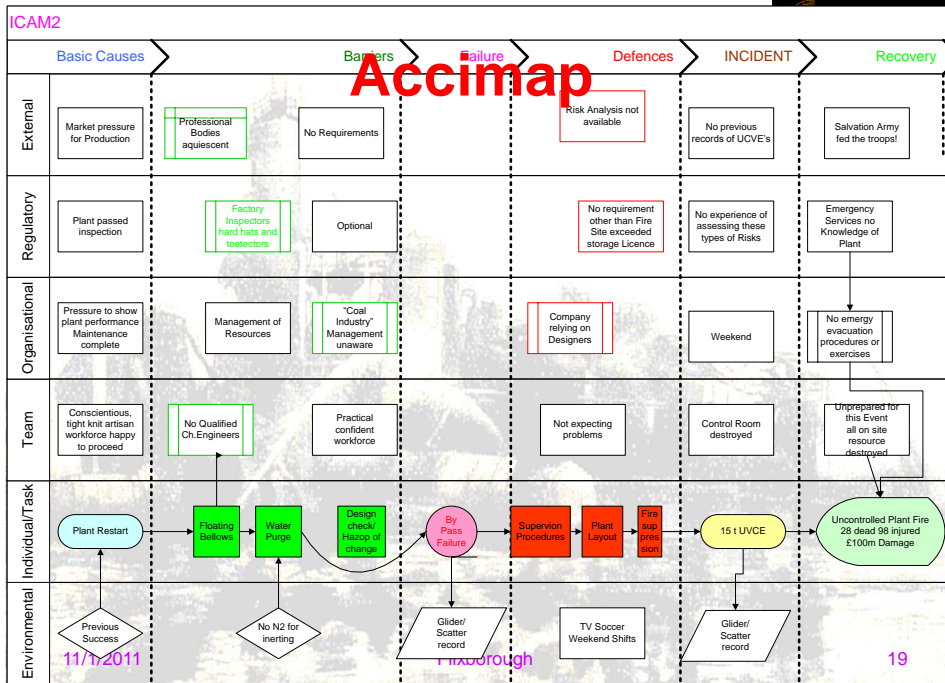
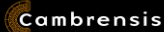
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Accident Sequence



Analysis

- Temporary by pass was unstable –
- **unrevealed fatal condition 1.** (Aneurism)
- Using water in start up would provide pressure surges above normal parameters.
(**unappreciated fatal condition 2**)
- Timing of failure to coincide with critical process temperature and pressure (Fatal **precondition 3**)
- Expected “bump boiling” phase reached in start up is independent corroboration of likely initiating mechanism (**Trigger Event**).
- Damage and dispersion patterns confirm the **consequences** as a large **Unconfined Vapour Cloud Explosion**.

Lessons

- Competences of Operators
- Design and Layout of Hazardous Plant
- Management of Change
- Specialist Inspectors
- Science of UCVE's – including
- Flame acceleration models,turbulence,
- 2 phase, effect of obstacles, semi confinement.overpressure prediction, etc..



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Other Theories

- Inquiry findings have potentially damaging and liability considerations for involved parties.
- 6 sets of QC/ Counsel/ Experts/ Consultants arraigned in adversarial setting to protect owners, designers, operators, etc.
- Overriding imperative to find alternative user friendly scenarios.
- Many still rumbling, although some of the wilder overpressure analyses have quietly been dropped.
- In a legal world ,Occam's Razor is a powerful way of distinguishing between convoluted options
- But the other branches of the event “Bow Ties” can and should legitimately be added in a complete risk analysis.

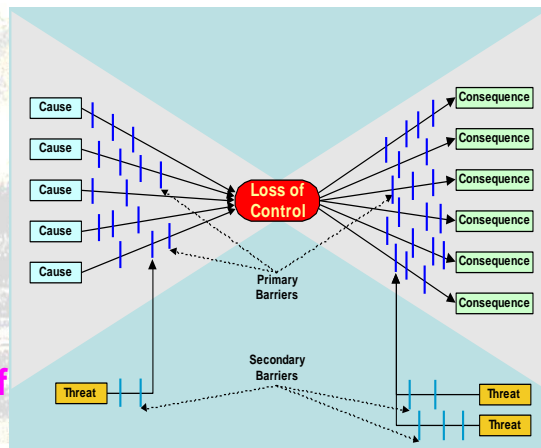
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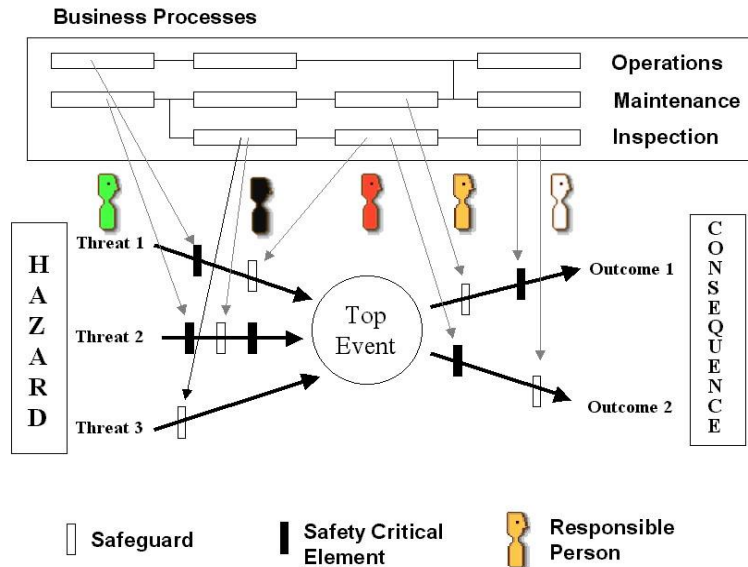
Insights

- Pragmatic definition of “Vulnerability”-
“Propensity to loss of control”
(i.e. Left Hand Side of Bow Tie)
- And “Resilience” –
“Effectiveness and depth of Defences”
(i.e. Right Hand Side of Bow Tie)



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Insight/Hindsight -An Integrated Safety Management System?



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Hindsight

What could we have done better?- Explosion

- Flashing champagne jets plus Joule Thompson adiabatic cooling meant Two phase cloud.
- At the time all models assumed gaseous phase propagation
- If droplets analogous to particles (miniature Bleve's i.e.- fuel rich)
- cyclic -C6 combustion- ideal for soot formation)
- Incandescent soot particles act as Dust Cloud not Gas cloud
- Radiative Flame accelerations now possible
- Likely Flixborough was a two phase explosion?



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Hindsight/ What did we learn?

- HSE Major Hazards Requirements (Buncefield?)
- Quantitative Process Risk Assessments (Waste plant Fires)
- Siting and Layout insights (Texas City)
- Unchecked modification of design or procedures (Longford)
- Companies can't delegate responsibility to contractors.(Piper Alpha)
- Or blame well meaning unsupervised, untrained initiative.(Chernobyl)

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Never Again?



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