ENGG404

Loss Incident Case Studies

An Inventory of Loss Incidents Used as Case Studies

Case 1: Sunrise Propane Explosion, Toronto ON
- It is used as a base case study to introduce many engineering safety and risk management principles.
- A truck driver illegally transferred propane from one truck to another which was a common occurrence at the facility.

Case 2: Piper Alpha Rig, Occidental Petroleum, North Sea, UK
- A leaking condensate flange lead to multiple explosions result in fires being spread through the entirety of the rig. By the early morning, the rig was destroyed.

Case 3: Czar B-52, The Imperative for Effective Safety Leadership and "Darker Shades of Blue"
- Leadership and the breakdown of management systems (loss of controls) in one of the most elite, high performance organizations one could identify.

Case 4: UCC Pesticide Plant, Bhopal, India
- Methyl Isocyanate (MIC) gas escaped due to failures in the management system. The escaped gas spread to the city of Bhopal resulting in the most number of casualties in this tragic industrial disaster.

Case 5: Exxon Valdez Crude Oil Tanker, Prince William Sound, Alaska
- Exxon Valdez oil tanker runs aground on the Bligh Reef resulting in 11 million gallons of oil being spilt.
- Many different individuals, groups, and the government were all accountable for the incident

Case 6: The Legal Side of Risk Management and the Hub Oil Incident, Alberta Justice
- Susan McRory, Crown Prosecutor, explains her experiences in the Hub Oil Incident and the lessons to take away from it.
- When you initiate a change, you need a strategy to overcome barriers, the resistance to change.

Case 7: BP-Macondo Oil-Field and DeepWater Horizon Rig
- High-pressure methane gas from the well, from the drilling riser, rose into the rig causing it to be ignited leading to an explosion.
- Transocean had attempted to work cheaply making the possibility of a blowout a higher possibility.
- Loss of focus on process safety with unbalanced focus on workplace safety.

Case 8: The MMA Train Derailment and Explosion, Lac-Mégantic, Quebec
- A freight train consisted of many tanker rail-cars loaded with diluted bitumen.
- The train was parked at the top of a hill, lost its braking action, began to roll as a runaway train, finally derailing in the core of a small town.
- Many tanker rail-cars were ruptured, spilling the contents, and igniting.
- Outcome: significant destruction of the town core and the loss of 47 lives.

Case 9: Nypro UK Chemical Plant, Flixborough, UK
- A cloud of cyclohexane escaped through a temporary "dog-leg" pipe connection.
- **Two Key Personal Lessons: 1) Know your limitations and 2) Ask for Help!**

Case 10: Lessons from STS-51L Challenger & STS-107 Columbia
- The STS Challenger Fuel Tank exploded seconds after launch due to the failure of the O-ring seals.
- The STS Columbia failed on re-entry, caused by loss of heat shield integrity, caused by insulation block strikes.

Case 11: Environmental Challenges
- Gives an overview of the Lake Wabamun and Lac Megantic disasters
- Is an exercise in critical thinking with respect to environmental impacts
- Takes a deeper dive into pipelines vs. railcars

Case 1: Sunrise Propane Explosion, 2008

Why Study the Sunrise Propane Explosion Incident 10-August-2008:
This event is a key model case study. We will re-visit this event several times in order to illustrate and learn about many different aspects, applications, and practices of ESRM process, system and program elements, and tools such as:

- hazard identification and risk analysis;
- safeguards and control measures;
- triggering event and incident escalation;
- incident causation model and incident analysis summary;
- impact on PEAP;
- incident investigation and root cause analysis work processes;
- immediate causes, basic causes, and latent (root) causes (loss of controls);
- application of risk management elements;
- application of risk assessment tools and methodologies;
- leadership in an industrial operation;
- and deficiencies or inadequacies in any of the above.

Summary Narrative of the Sunrise Propane Explosion:
"At approximately 03:50 ET on the morning of August 10, 2008, a large explosion occurred at Sunrise Propane Industrial Gases. This was followed by a series of explosions which sent large fireballs and clouds of smoke billowing into the sky. Large pieces of metal from the exploding propane tanks were ejected onto nearby streets and properties. Many homes and offices were damaged, windows were shattered, and doors were ripped from their hinges. About 200 firefighters battled the five-alarm fire that resulted from the explosions. The threat of further blasts and concerns about the air quality forced the police to conduct a voluntary evacuation of a large area in the surrounding community. Residents living within a 1.6 kilometres (1 mile) radius were told to leave their homes in the early hours of the morning.

The Ontario Fire Marshal's Office handled the investigation of the explosions. While the cause of the explosions has not yet been determined, on August 21, 2008, Ontario's independent safety regulator for fuels, the Technical Standards and Safety Authority, released a statement saying that just before the explosion, a truck driver was illegally transferring propane from one truck to another. The agency also reported that in November 2006, Sunrise Propane was warned about its lack of safety by not stopping the truck-to-truck transfers at the company's facilities, and that truck-to-truck transfers were a frequent and routine operating practice at the facility." http://en.wikipedia.org/wiki/Sunrise_Propane

Discussion Points About the Incident:
If you were the owner or general manager, or the newly-hired junior engineer on staff, with responsibilities for the safe loading, unloading, and transfer of propane, what would you have done? Why?

Some questions to ponder:
What physical components are required for a fire or an explosion?
Is this loss incident acceptable?
Was this an incident just waiting to happen?
What do we mean when an event can escalate?
What are some causes? Consider:

- Technical causes,
- Causes based on human factors,
- The absence of management systems or the systemic deficiencies or breakdowns in the management systems.

What are some process safety hazards and occupational hazards? What are some possible safeguards and control measures? Consider:

- Engineering Controls?
- Administrative Controls?
- Personal Protective Equipment?

As you can see in the lecture discussion of this incident, we've briefly explored an incident and:

- its impact on people, environment, and the business, as well as surrounding businesses,
- the various causes of the incident,
- the manner in which an incident can escalate,
- the loss of control or breakdown in management systems, and
- the aftermath of an incident.

Case 2: Piper Alpha Rig, Occidental Petroleum, North Sea, UK, (July 6, 1988) and "The Human Price of Oil", a Video

Review Video "Human Price of Oil / Spiral to Disaster" by BBC Panorama:

People:	167 workers killed, dozens injured
Environment:	Hydrocarbons (crude oil and fuel) were released to the marine environment
Assets:	Lost; no salvageable assets
Production:	Lost; no salvageable production capability (150,000 bbl/d oil, 1 billion litres per day natural gas) Fire disrupted productivity of other rigs

VIDEO: Piper Alpha DVD, Start: 00:28 (Ship) End: 22:20 (Helicopter Landing)

"Piper Alpha, Fire in the Night" h:mm:ss 1:29:04
https://www.youtube.com/watch?v=_PcDNRSsM24

"Piper Alpha, Seconds from Disaster - Explosion in the North Sea" h:mm:ss 0:46:54
https://www.youtube.com/watch?v=Nwbw5PHZnqk

Schematic of Piper-Alpha Relative to Other North Sea Platforms:

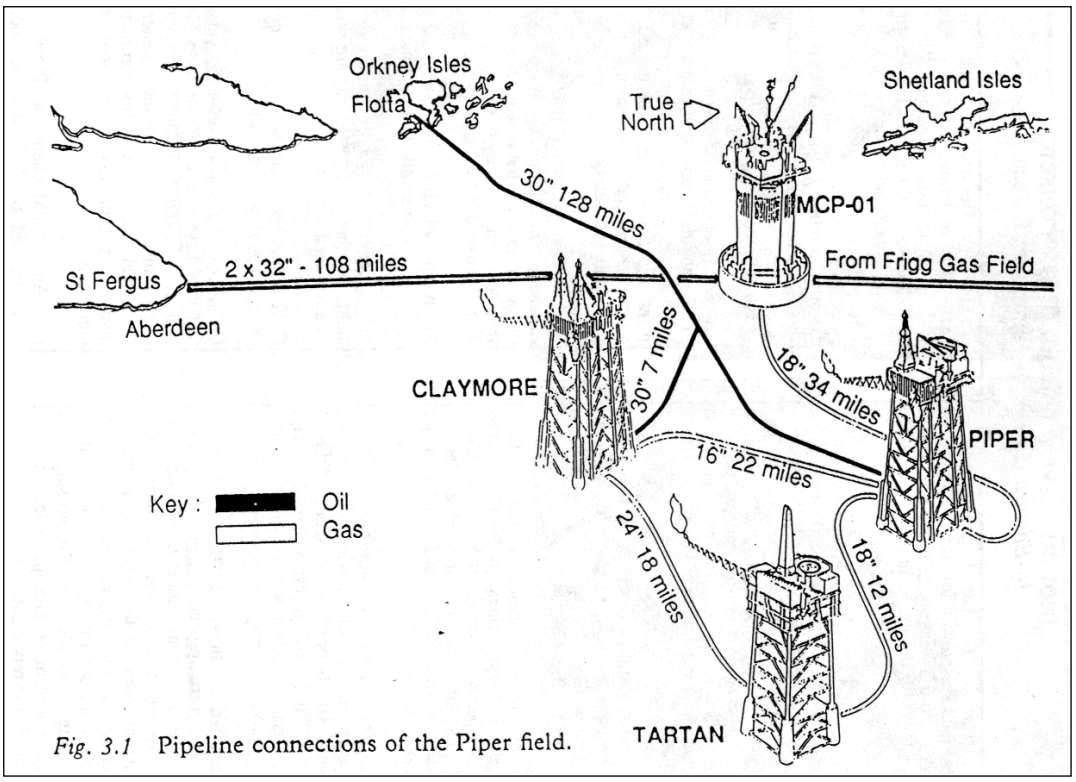
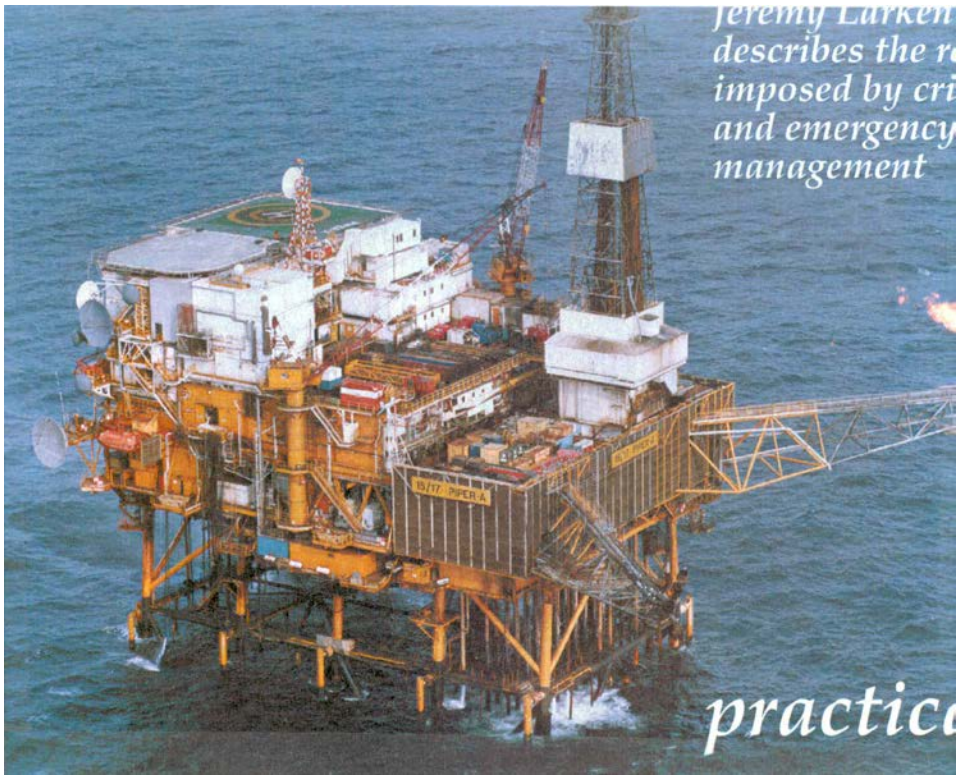


Fig. 3.1 Pipeline connections of the Piper field.

Piper-Alpha Prior to the Disaster:



Background Information (at the time):
Ownership (Share, %): Occidental Petroleum (36.5%), Texaco (23.5%), Texas Petroleum (20.0%), Thompson PLC (20.0%); The facility (off-shore and on-shore) was managed by Occidental Petroleum
British section of North Sea Oil production consists of 125 platforms, 113 to 193 km (70 to 120 miles) off the north east coast — about 20,000 people were working on the British platforms. The Norwegian offshore program was about the same.
Over the previous 20 years (1968 - 1988) approximately $150 billion was put into the British economy from this oil and gas production. Considerably more now.
The Piper Alpha producing 150 KB/D (24,500,000 Litres/Day) of crude oil and rerouting 934 million Litres/Day (33 mil SCF/D) of natural gas.
The "Piper-Field" was discovered in 1973. The field covered 12 sq. miles and the Piper Alpha platform was put in place to exploit the field. It started producing in 1976.
The original platform was a Gulf of Mexico design transported to the North Sea, which seemed to work in a very adverse climate.
There was no facility for recovering natural gas. A chapter for recovering natural gas was added later.
Products from well: oil, gas and condensate.
1976 - 78 — oil only. In '78 government policy on gas conservation caused the addition of a gas compression chapter ("C") to be added.
Large refinery type separation and compression process on the platform (about 1/4 acre in area — on land would take up roughly 10 acres).
Condensate re-injected back into oil and both pumped to Flotta (in the Orkney Isles) for storage and shipping (a terminal).
Dry gas compressed to 11,700 Kpa (1700 psi) and sent via Aberdeen into British gas network — see attached diagram.
Additional information about the rig:

- 474 ' from sea level to sea floor.
- drilling deck - work area - 133' above sea level
- accommodations 4 levels - 121' - 147' above sea level
- Firewater system (1 dedicated, 2 utility and fire, 1 utility) 1 electric and 2 diesel driven pumps. They also had the ability to add fire-fighting foam.

The Incident:
At 2200 hours on July 6, 1988, explosion of leaking condensate "cloud" in chapter "C" condensate pump room area. Approximately 30-80 kg (1/2-1 barrel) in a confined space caused a 0.20 to 0.40 bar peak over pressure deflagration.
The ignition source is unknown
Damaged oil lines causing serious oil fires with large amounts of smoke in chapter "B".
A second explosion in chapter "B" occurred about 20 seconds later due to the rupture of piping and equipment.
Control centre / power supply were badly damaged. This happened in "D" chapter next to gas compression chapter "C".
No deluge fire water was available because of the control room status. Also the fire water pumps were on manual because divers were in the area of the pump intake lines. This was a safety policy for the Piper Alpha platform but not for other platforms. A management decision based on what?
At 2220 hours catastrophic explosion when major gas line ruptured (approx. 18" diameter and 150 miles long operating at 1700 psi. A lot of fuel was released, about equal to the entire needs of Great Britain.
By early morning, the entire platform was completely destroyed.
165 oil workers died out of a complement of 226 on board. Of the 226 on board, 188 were contractors.
Production of oil and gas were reduced considerably.
North Sea Oil industry was immediately under a cloud. The British public could not accept the tragedy and a detailed investigation was undertaken.

Piper-Alpha after the Disaster:

Sequence of Events & Key Factors:

Inadequate risk assessment for gas compression works refit (fire-walls)
Lack of fire water availability (automatic deluge pumps switched to manual)
Inadequate mechanical integrity when PSV was removed
Inadequate management of PTW at end-of-shift hand-over
Unplanned trip of gas compressor and rush to return off-line pump to service
Initial gas release and explosion (blank was sub-standard)
Lost emergency shut-down capability (switch room not protected by fire-walls)
Prolonged oil fire (lack of isolation of oil production lines)
Gas pipe failure (flame impingement, inadequate explosion walls)
Death in the “safe-haven” accommodations (positive pressure design but lack of emergency escape drills)
Fire fighting only from one boat
No command & control during emergency
Decisions hampered - authority of Offshore Installation Manager (OIM)
Inadequate subsea isolation valve (SSIV on export lines)
Inadequate escape plans from off-shore platform

Causes:

Immediate Causes (substandard practices or conditions):

2 condensate pumps — one shut down for maintenance and blanked off, not known to nightshift crew.
No work permits or lockout permits were known of.
Second pump shutdown automatically for some unknown reason.
Crew attempted to start up first pump resulting in condensate spewing out from the improperly designed and installed "blind flange".
A confined vapour cloud exploded.
Calculations showed for an explosive mixture to fill the room, all that was needed was a 45 kgs leak. At 1700 psi that would be an 8mm-diameter hole (1/4 ") in a pipe or equivalent leak from the flange cover.
No firewater available. Pumps on manual control because of divers in area of intake.
The oil fire caused a failure in the major gas line producing a catastrophic explosion and fire. The shut off valves were right on platform. (The "Tartan Riser" came up to the 68' level then ran horizontally under the platform. The automatic shut off valves closed at 22:00 hrs. But the pipe ruptured under full pressure when it was overheated.) It took 55 minutes to depressure the pipeline of its contents.

Basic Causes (personal factors, job factors, design factors)

Very heavy pressure on production at all costs compared with Norway.
No risk analysis was carried out.
Because of oil price reduction they reduced their preventative maintenance activity to minimize downtime (is this rushing?).
Inspection by safety authorities was quite poor.
Safety inspectors under the same authority as those responsible for production. And that was the Ministry of Energy.
No overall safety and loss management program. Because of this incident, the government now requires companies to have what is now called the SAFETY CASE (a plan for safe operation).

Comparison: UK-Based vs. Companies Based in Norway:

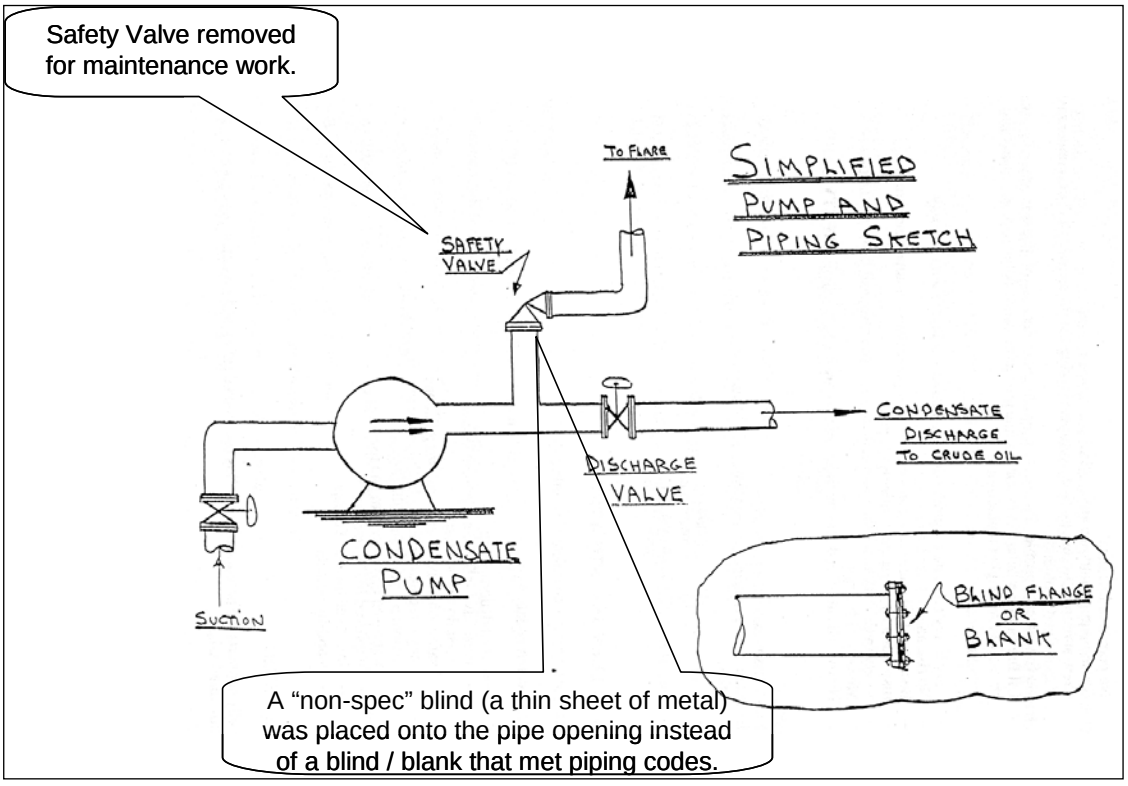
Compared with platforms owned and operated by Norwegian companies (Statoil, etc.), the culture of the Norwegian companies were characterised as:
Much less pressure on production.
Excellent safety management systems and risk analysis / risk assessment.
Their Priorities were:
People (valued)
Environment (valued)
Assets
Production

Lord Cullen Investigation
800 page report — completed November, 1990
106 recommendations
Key recommendations were:

- must have safety management system
- must do risk analysis
- safety objectives versus rules / regulations
- single regulatory body — health and safety executive
- temporary safe refuge for people
- improved permit system and usage
- improved fire protection
- improved means of escape
- standby vessels

Conclusion
The Lord Cullen Report totally supports the practice of first-class operational safety and loss management on a continuing basis. Further, the findings of The Lord Cullen Public Inquiry (the investigation report) changed the game for off-shore platforms in the industry …with the goal to prevent loss incidents!

Relevance to Operations In Alberta



Case 3: Czar B-52, The Imperative for Effective Safety Leadership and "Darker Shades of Blue"

Case Study - "Darker Shades of Blue":
Video, a reading, and classroom discussion on the reading assignment demonstrate the impact of lost leadership in an organization. References to recommended & supplemental readings & videos:
http://en.wikipedia.org/wiki/1994_Fairchild_Air_Force_Base_B-52_crash
http://www.youtube.com/watch?v=YQa4PpIkOZU (47 seconds)
http://www.youtube.com/watch?v=FUEhNKBi4DY&feature=related (9 minutes, 59 seconds)

Reading Assignment:
http://www.crm-devel.org/resources/paper/darkblue/darkblue.htm

Discussion:
Some open questions:
Overall what happened? (immediate cause – the focus on technical factors)
What caused it to happen? (basic causes – the focus on human behaviours)
What were the technical limitations? How were these limitations addressed?
Were there any early indicators that could have or should have been detected?
Were there any early indicators where the leader could have or should have intervened?
Why would senior officers (management) "let it slide" when they knew differently?
What were the weaknesses or failures in management i.e. the latent causes?
NOTE: The different types of causes will be defined in future chapters.

As you watched the longer video, you may have commented that the pilot's skills were "fantastic" or "awesome" or "nice, tightly banked turns", or "smooth, slow, and level". In fact, an informed observer would comment that the pilot is flying the aircraft well beyond its design limitations and that it is only a matter of chance that the aircraft does not disintegrate in flight or lose its lift.

This case contains lessons that can be applied to this incident, the Sunrise Propane incident, and many other incidents and cases that we will study in the coming weeks:

Any kind of operation has hazards and risks.
These hazards and risks must be contained, controlled, or managed through the implementation of control measures and safeguards, and these are implemented effectively with a sound risk management program.
Failure to secure the commitment of management / leadership oversight to ensure control measures are continuously maintained sets the stage for disaster to occur with significant consequence.

Questions about Leadership:
If you were appointed the Air Force Base Commander (the leader of all operations, including ground, take-off, approach and landing, and fly-by flights) after the Czar Incident, what would you have done? Why?
In reflecting on this event, you may want to consider these questions:
Why do we set policies and procedures?
Why are these rules bent sometimes?
Why do we as managers let them be bent?
What examples are set for current employees?
For new employees? And even visitors / guests / outsiders?
Can you personally relate to a similar story in your own working life?
What is leadership all about?
Did the leader have all the facts necessary to make an informed decision?
Were the leader's actions and words congruent?
Did the leader act in an ethical manner?
Did the leader consider the implications, both immediate and long-term, of their actions on employees?
Did the leader's actions promote a healthy work-place climate?
Did the leader enforce policy?

In industry, or for that matter, in any organization (corporate, government, institution; small, medium, or large; and sections, departments, or divisions within those organizations), good leadership is necessary in order to enable the organization to perform effectively, whether *for profit* or *not for profit,* or whether in the *public service* or for *private enterprise*.

Some operations have significant hazards and risks that are successfully managed every day without incident. These include the mining industries, the petroleum exploration / extraction / production / down-stream industries, chemical process industries, construction, maintenance, transportation, and almost any operation involving the transformation or transportation of materials. When significant hazards and risks exist, the stakes become higher and the successful **management of the residual risks** associated with those operations becomes **much more critical to the success of the business**.

Four Learning Points about Leadership:
Four learning points can be extracted from this case and from the brief look at other cases:

1. Without sound leadership in business and industry, the identification and control of risks breaks down and unacceptable events will happen.
2. Leadership is about commitment for the long term. In "Darker Shades of Blue", the command structure was undermined over several years, and it was never to be repaired without dismantling the organization and starting over.
3. Leadership is about setting expectations and modelling them though actions consistent with those expectations. Leaders set expectations by setting the example. This is called "Walking the Talk".
4. Leadership is a big and heavy responsibility, where leaders take on the accountability for their employees' actions as well as their own.

This is a brief introduction to the concept and idea of leadership within organizations, one which will be built upon throughout this course. **A key imperative from this course is the importance AND necessity of good leadership, especially concerning engineering safety and risk management in business and industry!**

Check the Engineer's Survival Guide:
Which of the four key points of The Engineer's Survival Guide apply?

Of Interest:
For the air force and/or vintage movie aficionado, watch **Twelve O'Clock High**. It has many lessons in leadership, and the hard decisions that challenge a leader. http://www.youtube.com/watch?v=zGVnjTMK8BE

Case 4: UCC Pesticide Plant, Bhopal, India (December 3, 1984): Lessons on Public Safety and Process Safety Management

For ENGG404: Some Points to Note During the Video for Discussion:

1. What were the impacts on PEAP?
2. Was "safety" a priority or a value? What integrity was shown?
3. Which of the guidelines apply from The Engineer's Survival Guide?
4. What were the immediate causes? Basic causes? Latent causes?

ENGG404: Identify Weaknesses in the Risk Management System and its 11 Elements:

Element	Weakness Yes or No?
Management Leadership, Commitment and Accountability.	
Risk Assessment and Management of Risks.	
Community Awareness and Emergency Preparedness.	
Management of Change.	
Incident Reporting, Investigation, Analysis and Actions.	
Program Evaluation and Continuous Improvement.	
Design, Construction and Start-up.	
Operations and Maintenance.	
Employee Competency and Training.	
Contractor Competency and Integration.	
Operations and Facilities Information and Documentation.	

Background and Introduction:

VIDEO: Bhopal: The Lingering Tragedy, 1984 DVD,

Review these segments of the DVD video:
Background - 00:36-10:06;
07:20-08:15; Leadership Message from UCC-Chairman: "Union Carbide has a moral responsibility" and "help them run their plant"
Exploration - 29:58-38:38;
33:15-33:42; Leadership Message from UCC-Chairman: "safety is the responsibility of the people who operate in our plants" (local line management is responsible for risk management in the plant)
34:30-35:25; UCIL-CEO: "certainly the operating responsibility rests with us"
36:30-36:45; Journalist: "grossly ineffective management"
36:45-37:47; "design defects" … Really?

Bhopal is a large central Indian city, the Madhya Pradesh state capital.

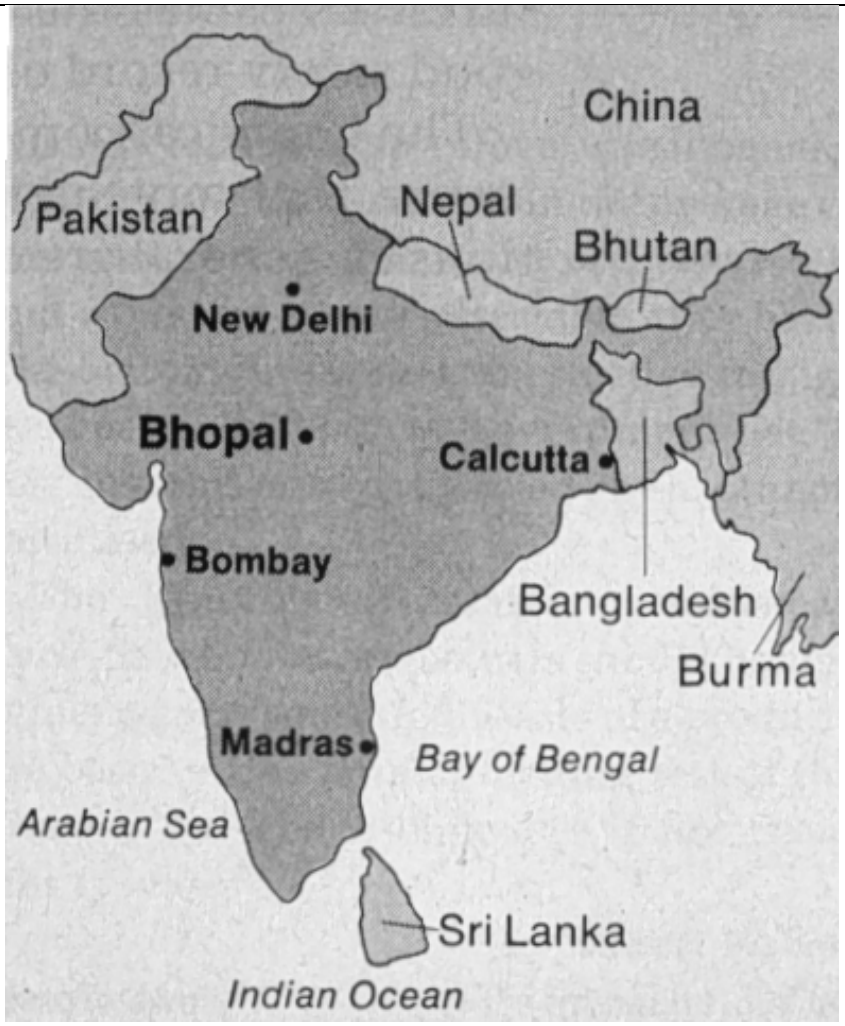
1961 population: 102,000
1973 population: 250,000
1981 population: 896,000
1985 population: 1,002,000

Much of this growth came from migration from surrounding rural areas.

Many migrants could not afford city housing and became squatters, creating slums and shantytowns.

By 1984, Bhopal had 156 slum colonies.

2011 population: 1,796,000



The Union Carbide plant located in Bhopal was owned by **Union Carbide (India) Ltd.,** or **UCIL**. Union Carbide Corporation held 50.9% of the shares of UCIL. The government of India owned~25%, and 24,000 other shareholders owned the remainder. The Agricultural Products Division of UCIL began operating the Bhopal plant in 1969. The production of methyl isocyanate (MIC), an intermediate in the production of Sevin® pesticide, began in 1978 as a result of a required backward plant integration.

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I**ncident and What Happened:**
At approximately 12:40 am, December 3, 1984, control room operator at Union Carbide Pesticide Plant in Bhopal, India, noticed very significant changes in plant operating conditions.
Storage tank containing Methyl Isocynate (MIC) - used for pesticide production
Temperature normally refrigerated, had risen to 25°C (77°F) (0°C [32°F] normal).
Pressure normally 14 - 172 kPa (2-25 psi) was increasing rapidly beyond 379 kPa (55 psi).
Operator, assistant operators, and MIC supervisor rushed to storage tank
Rumbling sound
Plume of gas gushing out of scrubber vent stack
The emergency flare had been previously shut down.
They took emergency action:
Tried switching on refrigeration - had been shut off
Started the scrubber on the stack - had been shut off
Sprayed water on escaping gases - had been shut off
These all failed, gas continued to escape; some plant personnel panicked and fled.
Approximately 40,000 kilograms. (40 tonnes) of MIC gas escaped as a "heavy" cloud over a 45-minute period.
Two large residential slum areas located directly across the street — shantytowns which had been allowed by the City Council with no consideration of risk.
In the panic of the night, well over 100,000 people were urged to flee.
Morning found death strewn over a stunned city.
Initially 2,500 people were killed (now the number is much higher nearing over 20,000 and expecting over 100,000 to have shortened lives.).
By most reports, the large majority of deaths were caused by gassing. However, many people were also killed from blunt injuries. The shantytown had few large streets or avenues for a quick evacuation (no evacuation plan existed). The people knew something was wrong (many felt the burning sensation in their respiratory system and others heard of the release) and panicked. The population flooded the streets and attempted to flee. The *few* people who owned cars drove as quickly as possible, often running over the crowd of people who were running on foot. Many people tripped, fell and were crushed by the crowd.
10,000 seriously affected
180,000 somewhat affected
Even in 1987 there are still 150,000 people suffering from adverse affects
100 workers in and around the plant at the time — only 1 affected and not fatally
Wind was approximately 10 km/hr (6.2 miles/hr)
100,000 long term effect - lung efficiency

Methyl Isocyanate (M.I.C.)
At normal pressure, boils at 38°C (100°F)
Volatile, with a vapour pressure of 348 mm Hg at 20°C (68°F)
As vapour, it is **twice** as dense as air and tends to settle out of still air;
a gentle wind moved it slowly along
Has a flash-point of -6°C (-43°F) meaning it will be a vapour in India but not in Canada in winter.

Toxicological Effects — Acute:
Before Bhopal, *not a single death* had been reported anywhere from MIC.
Hence, little toxicological data was available regarding the effect on humans but there was data on animal tests that can be used to determine possible unwanted consequences.
This knowledge increased rapidly when the first autopsy reports were available.
Causes damage to two systems:
Respiratory — much more severe
Eyes — somewhat recoverable
Most deaths due to respiratory failure:
Pulmonary edema — swollen tissue, with serious fluid, local dropsy
Bronchitis — inflammation of mucous membranes
Among the 150,000 others affected, main damage was to lungs — *capacity reduced by 50-60%*
Most common complaints were:
Eye irritation
Breathlessness
Chest pains
Vomiting
Muscular weakness

Long term studies are being carried out on:
Abnormalities in babies
Lung function with time
Effect on blood systems
Incidence of cancer

Immediate Cause:
“Water was allowed to mix with liquid Methyl Isocyanate in tank E-610.”

Contributing Causes Include:
MIC manufacturing a batch process and plant at only 40% capacity — due to low demand.
October 22 — last batch made before disaster; 40,000 kg (40 tonnes) stored in Tank 610 — maintenance work was planned for the coming morning.
The plant had several safety features:
Refrigeration system to keep MIC cool — particularly in summer months — not on
Vent gas scrubber with caustic neutralizer — not on
Water-spray pipes that could be used to control some quantities of escaping gases — not on
Flare tower for burning small amount of gases — not on
With the batch process manufacturing MIC shutdown — parts of the plant were dismantled for maintenance:
Flare system shutdown to repair pipe
Refrigeration shutdown with refrigerant drained
Nitrogen pressure system on tanks developed faults
Pipes were flushed with water before repairs
Leaking valves and "open" valves allowed water to flow into MIC tank 610
Should have inserted a "blind", but inexperienced mechanical crew did not
500kg of water flowed into tank 610.
Water reacted with MIC in presence of metallic impurities (acted as catalyst) and caused a *tremendous exothermic reaction* — temperatures approached 260^{o}C (500^{o}F) (probably exceeded tank design criteria).
Secondary chemical reactions also took place. Rapid release of vapour through relief valve system.
Scrubber system was designed to deal with gases alone, not mixed with liquid — it failed to operate and therefore had to be started up.
Flare was down for maintenance.
Refrigeration system was out of commission.
Water sprinklers could not throw water high enough to neutralize the escaping gases.
Hence, toxic gases were able to bypass all these safety features.

Proximity to Community:

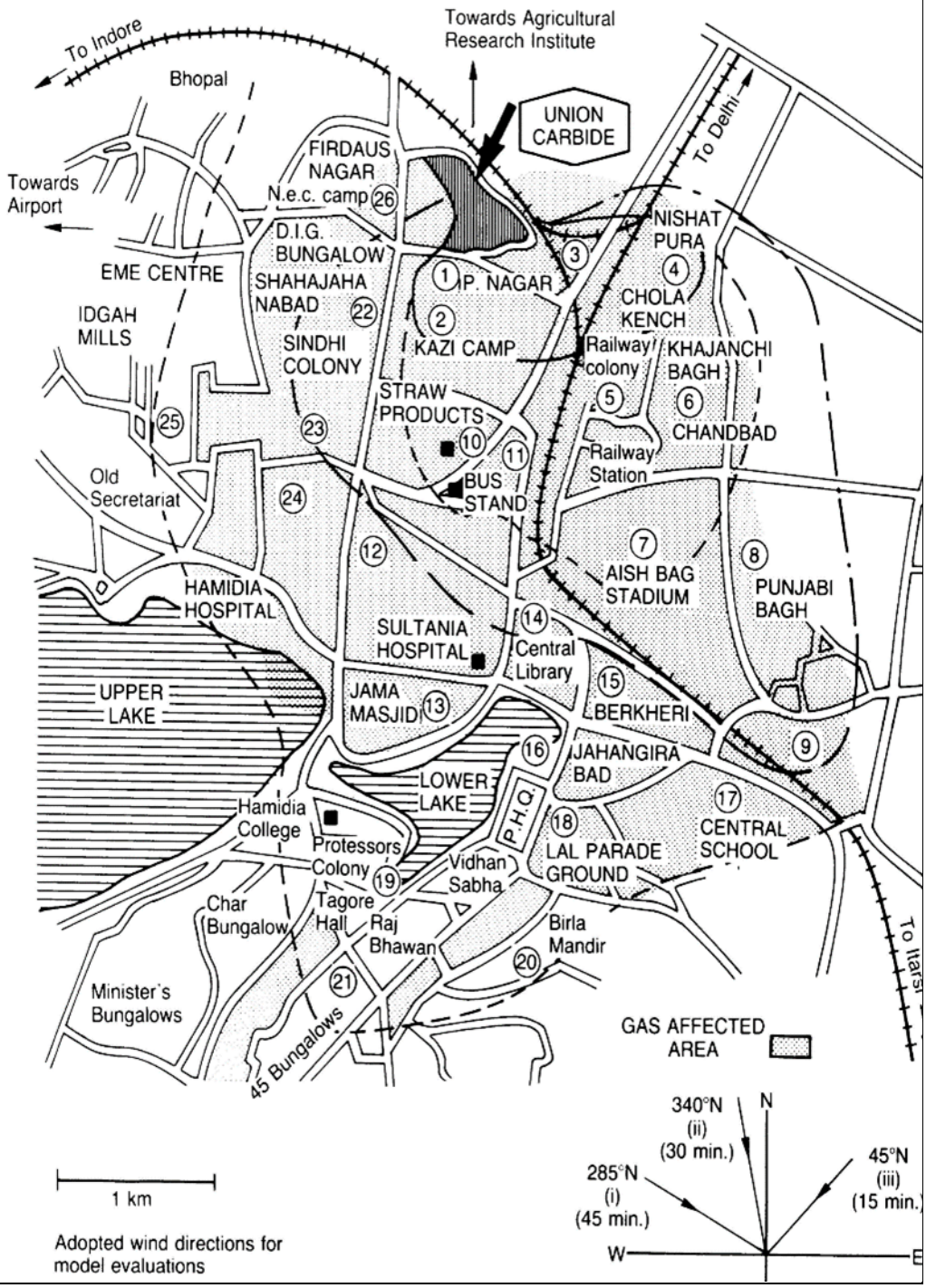
Two slums were located very near the UCIL plant, in an area not zoned for residential use. The plant fence-line can be seen in the photos.

When the UCIL plant was first built, it was situated in an industrial area with no residential areas nearby.

Because the shanty-town built up around the plant over time, many thousands of people were exposed to a cloud of MIC when it was released from the plant in 1984.

Factors contributing to the severity of consequences included MIC vapors being heavier than air, the release occurring at night when dispersion is less, and hospitals and dispensaries being unable to cope with the number of victims.

Reprinted from J Haz Matls 17, M.P. Singh and S. Ghosh, "Bhopal Gas Tragedy: Model Simulation of the Dispersion Scenario," p.1, © 1987, with permission from Elsevier



UCC Pesticide Plant Disaster, Bhopal, India 3-Dec-1984 and the Impact on PEAP:
Bhopal, India, at 12:40 AM (early morning hours) Monday, December 3, 1984
(Sunday at 12:10 PM Alberta, 2:10 PM Ontario)
A vapour cloud of methyl isocyanate, a highly toxic substance, was released

2,500 immediate fatalities
25,000+ total fatalities
100,000+ other offsite injuries

Three Design Questions to Consider:
Even if all these systems had been working, could they have handled the large mass of vapour?
How much water is required to set off a catastrophic event, with or without metallic impurities?
They took a risk. Did they know how much risk and was it an "acceptable risk"? Did they have their guard down? Were they complacent?

BASIC CAUSES:
As determined by Paul Shrivastava, Executive Director Industrial Crisis Institute, New York.

Human Factors
Plant losing money, running at 40% capacity
Low morale
1982 Operational Safety Survey indicated safety rules, permits, etc., not being effectively enforced by Union Carbide Inc.
Best employees leaving, *80% of workers* training in USA had left.
Between 1980 and 1984, manning *cut by half*.
No maintenance supervisor on second and third shift — they were responsible for ensuring proper *blanking* of lines before water washing.
Not a computerized plant, hence human backup very important.
Rumors of sabotage upset bringing systems under control.

Organizational Factors
Bhopal Plant was an unprofitable plant in an unimportant division of the corporation.
UCIL was *one of fifty international subsidiaries* of Union Carbide — 2% of world sales, 2% of profits.
Bhopal Plant was one of 13 UCIL Plants, operating below 40% capacity for several years due to markets.
Was not receiving much attention or support *from top management.*
Because of above economic conditions, the plant was *up for sale* at time of disaster.
Top Management Discontinuity — 8 plant managers in 15 years, many came from non-chemical industry backgrounds. Result: systems, procedures, emergency response and training all suffered.
The parent company did an audit in 1982 and identified 10 major areas of concern — 5 of these contributed to the accident: instrumentation, permits, procedures and maintenance.
The plant had no contingency plans for dealing with major incidents — lethal nature of MIC was not totally understood by the Plant and the community.
Management systems were of a poor quality, including Safety and Loss Management.

Technological Factors
Large storage of bulk MIC in an operating area using manual non-computerized control systems.
Tank 610 was not under continuous positive nitrogen pressure for 2 months — allowed metallic impurities to enter (acted as a catalyst).
Without these impurities, reaction would have been much less severe.
Plant design and piping systems allowed a pathway for wash water to back into tank during flushing operations (large quantities).
Scrubber system designed for vapour only.
No radio communication system for operating staff.
Note: This plant was built in an area where a household with a single light bulb was a rarity. A “dial telephone” was “high technology”, even in 1984! (Widespread use of touch-tone telephones in North America was about 10 years old.)

Poor Government in Bhopal
Rapidly developing city sought and obtained sophisticated western industrialization without investing in industrial infrastructures.
Bhopal selected as capital of the State of Madhya Pradesh in 1956 — population grew rapidly from a fairly small town to approximately 800,000 (especially in 1974-84).
Plant site originally had little population around it.
Because of rapid population increase, shantytown areas grew around the Plant — densely populated, poor streets and lighting, etc. Government did not cope with this.
A combination of social, local infrastructure, lack of awareness and lack of community preparedness added severely to the results.

Latent Causes:
Lack of management / government attention
Not knowing how sloppy the operation had become
Failure to ensure known actions were carried out
Essentially a complete break-down in the Risk Management System & Program

Overall Lessons
Plants like these must have first class design and technology with built-in reliable safety features and must be kept up to date over the years by capital investment.
Management must be totally committed to Safety and Loss Management — both at the local and corporate levels, independent of the local economics (or shutdown).
Location of plant with respect to population areas should be a major consideration.
Infrastructure of surrounding areas must be supportive — roads, water, sewers, access to fire stations, emergency measure organizations, etc.
Combined knowledge and experience of operating, maintenance, technical and management personnel must always be maintained at a high level. This might require some non-local expertise. Today we have retired much of this knowledge. Does this mean we have increased our level of risk?
Strength of organization needs continual risk assessment.

Technical causes: multiple protective safety systems were not functional. Your Response (Engineer's Survival Guide): "# 4) Pay attention to failures in safety systems and take action! "

Inherently safe design: Why 40,000 kgs of MIC in inventory?

Risk management system weaknesses: Good design not maintained by local management lead to compete breakdown of risk management system. Local line management responsibility!

Why did local management allow system to breakdown?
Why did global corporate management allow system to breakdown?

Local government responsibility for allowing encroachment?

NOTE:
A conference held to mark the 20th anniversary of the incident showed there have been much learned from the incident and much progress made in the way of analyzing operations for possible risks. However implementation of policy by both companies and local governments has basically not effectively taken place. Movement towards stronger implementation is driven by some ethical measures by industry but for the most part the threat of legal action is the main driving force.

Balance in Case Studies
Obviously, the parties involved (Union Carbide, the People of Bhopal and India, and other shareholders), and third party activists do have different perspectives.
Thus it is always important to balance all available information and perspectives of stakeholders when forming policies that drive action.
The same applies today, in Canada, about northern development.
Consider these web-sites:
http://www.bhopal.com/
http://www.bhopal.org/
http://en.wikipedia.org/wiki/Bhopal_disaster
http://www.greenpeace.org/international/en/multimedia/slideshows/bhopal-the-world-s-worst-ind/

Case 5: Exxon Valdez Crude Oil Tanker, Prince William Sound, Alaska, & A Lesson on Environmental Impacts and Complacency in the Workplace

Introduction:
This case study explores the impact of an entirely-preventable incident that severely impacted the environment, and the breakdowns in various management system elements that ultimately caused the incident.

VIDEO: Exxon Valdez DVD, Start: 00:28 (Ship) End: 0:16:00 short, 0:27:00 mid, 0:54:00 full

Sequence of Events That Evening Leading up to the Incident:
Exxon Valdez oil tanker departed Port of Valdez 9:00 p.m., March 23rd, 1989 bound for Los Angeles/Long Beach, California.
Loaded with approximately 53 million gallons of Alaska north-slope crude oil.
Two year old vessel, single skin high strength steel construction: 987' long, 166' wide, 88' deep
In lieu of double skin bottoms, the ship was constructed with 11 cargo tanks and 7 segregated ballast tanks.
20-man crew including Captain Joe Hazelwood.
11:15 p.m., cruising at 12 knots, reaches rocky point where harbor pilot departed from ship (routine).
Hazelwood radided the coast guard to say he would move ship from outbound lane to inbound lane to avoid ice.
At approximately 11:50 P.M. Hazelwood turned over control to Third Mate Cousins and ordered him to make a right turn back into the outbound lane when vessel reached navigational point near Busby Island - 3 miles north of Bligh Reef.
Second Mate Lecain was exhausted and asleep - would relieve Cousins in a couple of hours.
Captain went to his quarters to catch up on paperwork.
11:55 p.m. ship passing Busby Island - Cousins phoned Captain to say he was altering to correct course.
Log shows this didn't start to happen until approximately 5 minutes later.
Valdez was not responding well to Cousins' order to turn - possibly counter rudder maneuver to slow swing - Helmsman Robert Kagan.
12:05 a.m. - Sensing trouble, Cousins ordered a hard right - too late.
Valdez runs aground on Bligh Reef at approximately 12:10 a.m.
Captain immediately to the bridge - slowed ship to keep from sliding off reef and doing more damage. Held ship in position.

Losses and Impact - October 1, 1989:

Oil spilled	11,000,000 gallons
Shoreline oiled badly	1,090 miles
Shoreline "treated"	1,000 miles (Exxon)
Shoreline still to be cleaned (as of Sept. 1989)	1,000 miles (Alaska State)
Dead birds	33,000
Dead otters	1,000
Clean-up cost so far	$1.28 billion
People involved in clean-up 12,000	
Vessels and planes used	1,385
Waste from clean-up	24,000 tons
Oil recovered	2.6 million gallons
Oil evaporated	3 to 4 million gallons
Oil unaccounted for	5 to 6 million gallons

Captain Joe Hazelwood (42) fired for negligence, at the end of March 1989.
Charged by the State of Alaska for:

- Operating a ship while intoxicated
- Reckless endangerment
- Criminal negligence discharging oil

Exxon – 170 lawsuits filed
Exxon claims paid to fishing industry: **$75 million** at the time

Discussion:

Investigation of the incident turned up several points that should have been managed better than they were:

There was a lulled sense of security:
Alyeska risk assessment study indicated major spill once every 241 years.
9,000 safe passages since mid-seventies - 12 years trouble free.
Alyeska consortium of 7 major oil companies, producing oil from north slope of Alaska - owned share in pipeline and port.
Had contingency plans reviewed by state and Feds.
Major oil shipping companies had improved, reviewed their response capabilities after the
Amoco Cadiz oil tanker sinking 1978:
6-times as large a spill (68.7 million gallons).
Coast of Brittany, France
Exxon Executive 1978: felt the Amoco Cadiz was a case where they “learned our Lesson".

Evidence of not paying attention:
6,000 spills/year reported to U.S. Coastguards
6 of these as large as 100,000 gallons
Cutting of staff by:

- Alyeska
- All shipping companies
- Alaska State
- Coastguard

No recent simulations.
Research and design projects started because of "Cadiz", all suffering from lack of funds or stopped. (Example being the Ohmsett test facility).

> *“This typically happens. Major incidents seem to create a wave of outrage and interest to prevent future incidents. However, memories are short. Commitments do not seem to carry much weight unless you are personally involved.*
>
> At the time, the public and governments had a shorter memory. Today, we have less tolerance and a long view both forward and backward.

Legislation slowed down or stalled on:

- Double bottom vessels
- Responsibility division
- Response requirements
- Ships crew competency
- Strengthened laws for polluters

Emergency Response:

- Too little too late.
- Magnitude of disaster was way above effective response.
- Did not have technology, procedures, and at-the-ready response teams to effectively respond.
- Cannot just do nothing and let "nature" do the repairs. This is politically unacceptable.
- 11,000 workers on remote coastline can do significant damage to the environment:
- High pressure washing
- Hot water scouring
- Rock polishers
- Once it went from containment (overwhelmed) to clean-up, large effort, major resources with less than desirable results - public outraged.
- Exxon wanted to use dispersants - not allowed by State Government. Conditions of sea probably not correct. Dispersants will have their place in the future.

Exxon’s organization and response:

- In almost all of its operations, had a first-class record in safety and risk management worldwide.
- From day one, admitted their responsibility - "we are as horrified as anyone else".

- Poured money and resources into their effort.
- Want all current and future research efforts to be "open" and unfettered by lawyers.
- Did not practice effective proactive risk management in this area.
- Did not handle communications, P.R. and news media well - tended to keep underplaying the event.
- Appeared somewhat "arrogant" as environmentalists hounded them.
- Coastguard felt Exxon overly criticized - "make Exxon pay for sins"
- Opposition - If the public had known the "true" risk and that present day response could not handle - all hell would have broken loose.
- Was firing of Captain correct?
- EXXON pleaded guilty and was fined $100,000, plus costs to clean up ($1 billion) and restore the shoreline.

Captain Joseph Hazelwood:

- Tried in court and found responsible.
- Subject of another study
    - He had graduated at the top of his class and was highly considered. So what happened?

Present and Future Improvements

- Sustain research and development at a much higher level
    - Containment equipment, procedures
    - Clean-up equipment, procedures
    - New technology:
        - Dispersants
        - Biological destruction
        - Means of delivery
- Organizational Improvements
    - Response teams
    - Response equipment location
    - Command post
    - Simulations and critique
- Design and deploy improved design tankers:
    - $125 million - single bottom
    - $140 million - double bottom
    - $160 million - double hull
    - Additional improvements

- Tougher legislation
- How to take advantage of present "anger" and public awareness
- Proactive direction
- Pilot vessels further out of harbours: 975 miles at Valdez now in force
- Much improved navigational equipment and coast guard monitoring
- Risk analysis of major routes and harbors
- Tougher standards for crew selection and ongoing testing.
- Less pressure to reduce crews
- Improved simulation and training
- Can the boredom of work be reduced?
- Combined high level, industry, government, coast guard management team ensuring continuous improvement.
- Others including reflecting "true" cost of transporting oil.

So Why Did This Happen????

The right steps were taken at the beginning when the project was planned. The people of Alaska and particularly Valdez wanted assurance their piece of paradise would not be harmed by a spill of oil. The result was a "risk assessment" pointing out the probability and consequence of a major spill.

Armed with the study the Alyeska Consortium, the US Coast Guard and the community of Valdez developed rules and regulations and emergency plans before anyone was allowed to ship oil from the port.

People are funny. For some reason we always become complacent even though we fear the consequences. Here the consortium and the community let their guard down. They accepted less

emergency preparedness, they accepted lower staffing and equipment to not be available as originally planned.

The EXXON captain decided to do paper work while his ship was taking a risky course to avoid ice. Even though he had no pilot on board any more because it saved money.

Complacency is one of the biggest challenges for management to handle. Lectures later on Human Factors try to address some of what makes us as people a big problem.

Complacency – individual and organizational - is certainly a challenge.

Update:

EXXON (*spent $2.5 Billion in 1989 on Clean-up)*

- Plead guilty to Environmental Laws - Civil settlement
- $100M file - largest in history
- $1B damages for clean-up and restoration of a 10-year period.
- $100M to Fisheries - more to come.

Spring 2005: EXXON ordered to pay additional 3.2 Billion to Alaska businesses

Civil Cases

- 300 law suites by Alaskan natives,
  - Other residents and private businesses,
  - Court cases - Summer **1994**

Ship's Captain

- Fired from Exxon - procedures.
- Tried on criminal negligence, discharging oil – lost license, $50K fine, suspended sentence, + 3-years.
- Boston Harbour Tug Boats.
- Now teaching at Marine School.

Alyeska Consortium - Coast Guard - U.S. Govt. Agencies

- Much improved cooperation
- Much improved preparedness and facilities
- More frequent simulations
- Research into better methods, practices, procedures
- Improved radar installations
- Ship design

EXXON

- All the above
- Plus much improved safety and loss management program/practices for whole company and affiliates

Prince William Sound

- Recovered faster than expected
- Still some pockets of damage
- Fisheries and marine life recovering

Lessons For Those In Responsible Positions:

At some time in your careers, you will be in a responsible position; in fact, almost from “Day 1”. Your scope of responsibilities and span of influence will grow as you take on new challenges and successfully reach the objectives. If your leader offers you a new area to look after, a new project, a new job, or to take over on any one of those, your leader has confidence in you will be successful. This is a characteristic of a well-run organization.

So, when in your position of responsibility, and to exercise your responsible role to the best of your abilities, here are some key lessons:

- When on duty, you must be fully competent (no impairment).
- If you have a health problem, **seek help** and report it. Think of consequences of error in judgment.
- Know all the rules, regulations, etc., and perform above these standards where possible - meeting them is not always enough.
- When you find deficiencies (gaps or errors) in the company’s rules / internal regulations, take action to correct.

- Be very careful when you are dissatisfied with work situation - do not let this interfere with your competency and judgment.
- Be a crusader for safety and risk management, keeping current on all aspects.
- Intelligently critique those groups, departments, etc. that adversely affect your performance. Offer “constructive feedback” in a positive, sensitive, and diplomatic manner. This is very difficult to do, and if done badly, it can affect your reputation, career aspirations, and opportunities for promotion. And you cannot just say nothing. Why? If you’re in a management position / leadership, and you are being adversely affected, more than likely it is impacting your workers, and you are responsible for them.
- Keep the Engineer’s Survival Guide at hand, and put into practice its key points.
- In almost all instances, if you are:
  - Competent
  - Professional
  - Continually updated in your field of expertise
  - Ethical, and
  - Maintain your Integrity

Then this type of disaster would not occur, and should not have occurred!

References:

Exxon Valdez Oil Spill (1989), Wikipedia, http://en.wikipedia.org/wiki/Exxon_Valdez_oil_spill Accessed 23-Aug-2013

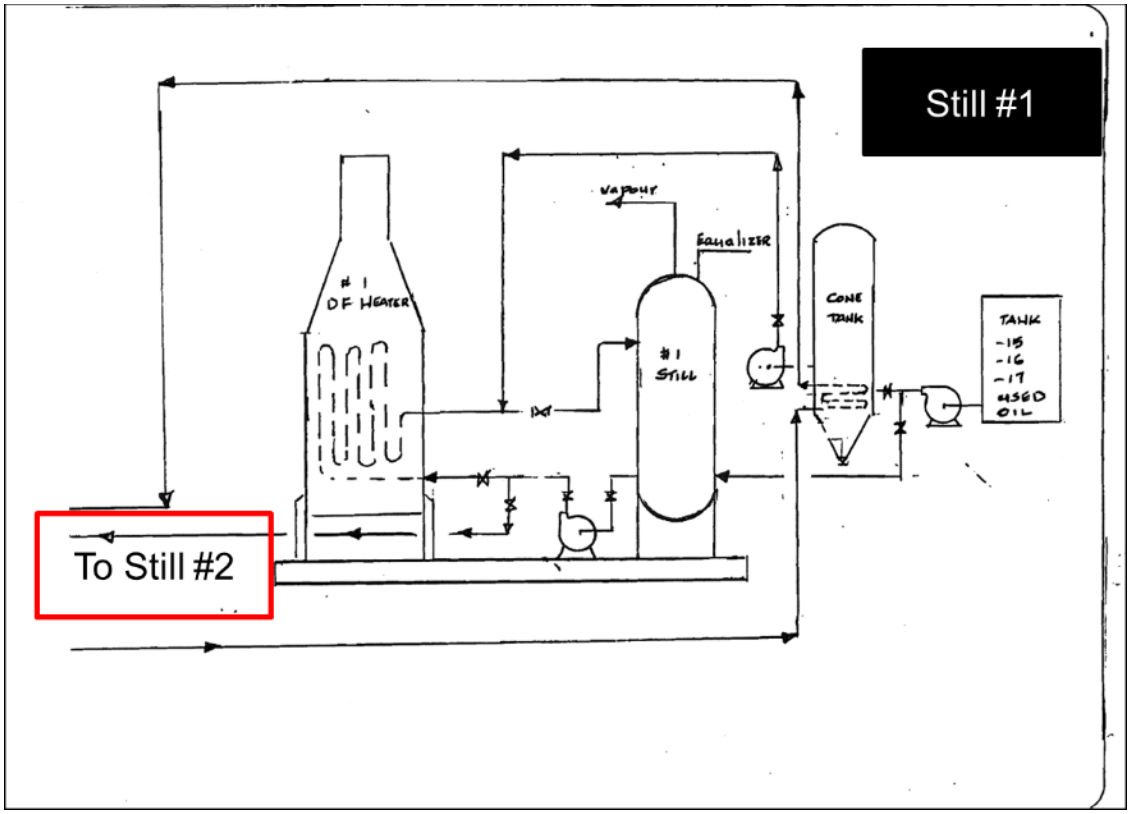
Exxon Valdez Oil Spill Trustee Council, web-pages, http://www.evostc.state.ak.us/facts/ Accessed 23-Aug-2013

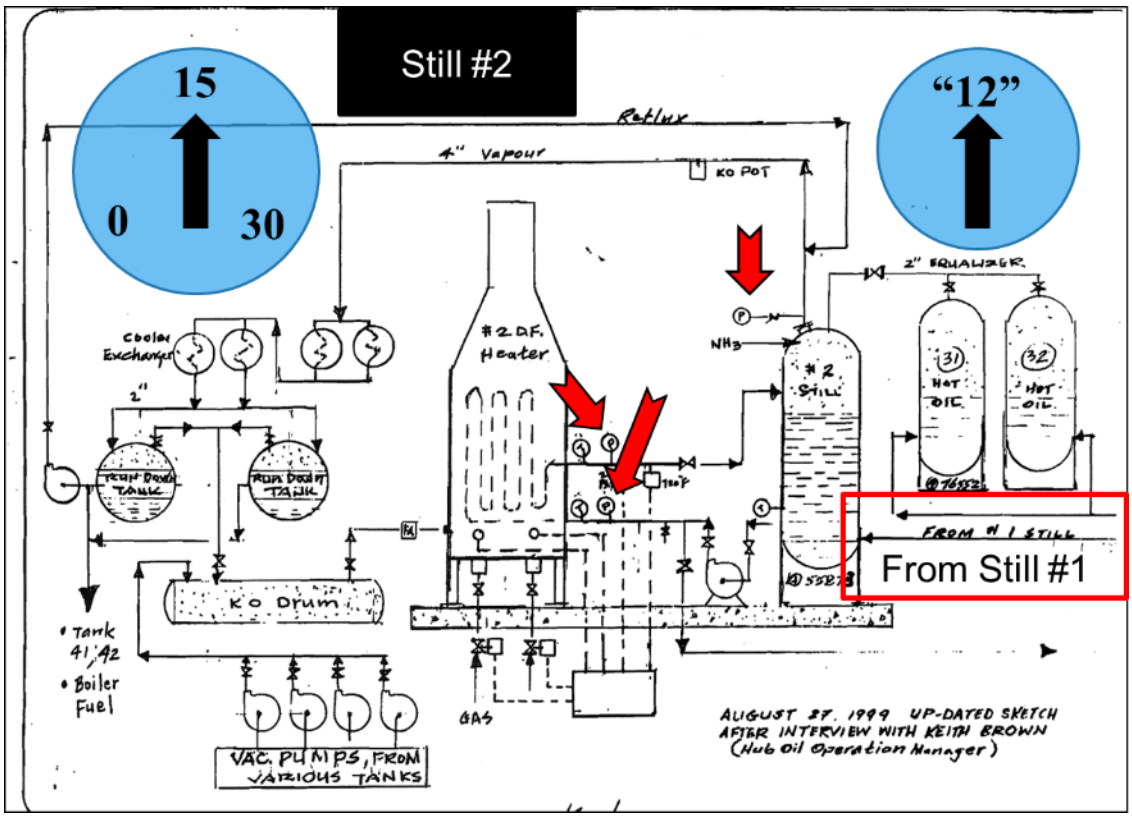
Case 6: The Legal Side of Risk Management and the Hub Oil Incident

Introduction and Background:
The guest speaker is Susan McRory, Crown Prosecutor - Environmental, Specialized Prosecutions Branch, Alberta Justice (retired). She led the criminal prosecution against Hub Oil after the incident. The investigation took three years before it was brought to trial. In the trial, the Crown was able to prove that Hub Oil was criminally responsible. She will share her insights into what happened, why, and what needs to be done to prevent tragedies such as this one.

Susan McRory worked in criminal justice to prosecute the typical crimes, but for the latter 20 years of her career, Susan had been prosecuting companies under Alberta's environmental laws, the Alberta Environmental Protection and Enhancement Act. This seminar dates back to a personal commitment made as a result of the Hub Oil Incident. Her belief was that the typical crimes cannot be prevented, it's already done and the roots of the crime are in society at large; however, environment prosecutions can provide incentives to motivate organizations to abide by the laws as well as to implement good environmental practices in order to prevent environmental incidents. This seminar demonstrates her commitment.

Schematics of the Hub Oil Refinery System:





The Incident:
On August 9, 1999, in the industrial part of Calgary, a pressure vessel ruptured and quickly escalated into a fire and series of explosions, eventually destroying the plant.

Video highlights: The Hub Oil Loss Incident, 9-August-1999
00:00 – 01:00; The video starts within minutes after the initial explosion; listen for the explosion at 0:25
03:05 – 03:40; Watch for the one supervisor at 3:09 (pause)
06:00 – 06:25; Listen for the high-pitched whistling; jet-fire at 6:10, supervisor appears at 6:15; fire-fighters continuing to struggle with water blast; listen to the audio at 06:45 – 07:00
07:55 – 08:15; front-line firefighters leave
10:50 – 11:20; observe the large pieces of shrapnel during and after the incident
19:20 – 19:40; observe the destroyed firetruck
19:55 – 20:25; evacuation, smoke emissions, explosions
21:30 – 21:50; oil residue contaminating the local drainage and sewer systems, and eventually the natural water ways

Two workers were killed.

#2 Distillate Shell,
Photograph courtesy of Alberta Justice (a public record).

Some thoughts from Susan McRory on Hub Oil:

When you are compelled to initiate a change, you need a strategy to overcome barriers, the resistance to change. Those barriers are closely held beliefs such as "it has never happened here", or "it's not broken so don't fix it", or "my grandfather / father (or whoever) built this / ran it this way, so who are you to tell me ..."

You can use the rational approach, the business case for engineering safety and risk management, risk assessments, impact on PEAP. And sometimes this will be successful, but you are negotiating with the rational mind, the non-emotional, and it might not be enough to overcome the irrationally-held beliefs.

So, you need to be prepared to negotiate with the irrational, emotional mind. You need to use the emotional argument, and you will need to make a passionate argument, one that is closely held by your beliefs, and that appeals to their beliefs. You could use your personal experience; however, not too many early-career young people have had a significant emotional experience! So, you need to personalize it from their perspective in order to convince them that much more is at stake than they realize.

Case 7: BP-Macondo Oil-field and DeepWater Horizon Rig (20-April-2010 to 15-July-2010)

Recall Our Benchmarks and Our Practical Applications:

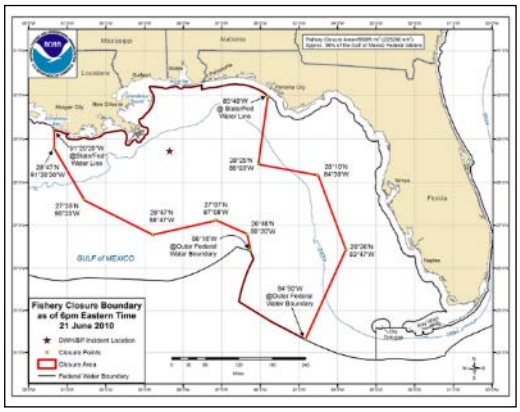
The Engineer's Survival Guide:
Understand company values!
Understand your program!
When you make decisions, put safety ahead of any other objective!
Pay attention to failures in safety systems and take action!

Risk Management System and 11 Elements

Exploration Questions for Case Study Lectures
As with any case study, you should analyse for these questions:
Was "safety" a priority or a value?
What Risk Management Elements were weak or failed?
Which of the key points of The Engineer's Survival Guide apply?

Introduction:

This case study explores the impact of an entirely-preventable incident on PEAP, and the breakdowns in various management system elements that ultimately caused the incident.



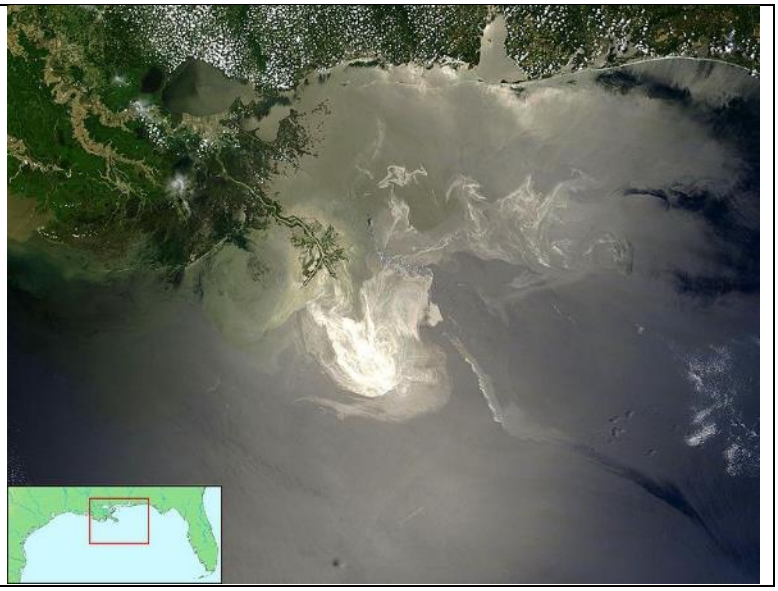
The Loss Incident:

- Date of Loss Incident: 20-April-2010 to 15-July-2010
- Platform: Deepwater Horizon Drilling Rig

- Location: The Macondo Prospect (MC252 U.S. Minerals Management Services), Gulf of Mexico off the coast of Louisiana.
- Rig Operator: TransOcean Ltd., offshore drilling contractors and rig owners
- Mud Contractors: Halliburton Company, oil field services
- Prospect Rights Operator and Developer: BP plc, oil and gas company; chartered DwH from Transocean.

Blowout started on 20-April-2010 until capped on 15-July-2010; total of 87 days of unimpeded crude oil flow from the well into the marine environment. The blow-out caused an explosion and fire on the rig, with catastrophic losses. The spill to the environment contaminated large regions of shore-line and disrupted fisheries and tourism in the Gulf of Mexico regions of the U.S.

Impact on PEAP:

P: 11 killed, 16 seriously injured **E:** inestimable impact on the marine environment, wildlife, and fisheries **A:** total loss of the rig ($350MM) and the well prospect; fines, clean-up costs, and litigation in the tens of billions of dollars. **P:** Deepwater Horizon, as a drilling rig and not a production rig, did not secure the well in a condition for a production rig to tap into the reservoir. Broad interruptions for US Gulf of Mexico offshore drilling industry; and Significant regulator intervention with regulatory impact. Offshore exploration and drilling was halted for months, and indefinitely suspended in some parts of the US offshore areas.	

Documentaries on Video:
WDR/AD / Anthro Media Production - Documentary: “Profit, Pollution, and Deception”, Duration 45:02
http://www.youtube.com/watch?v=R5vIGBG0wgg ; accessed 21-Aug-2014
http://www.youtube.com/watch?v=8zGFvzMMO9w ; accessed 21-Aug-2014
Video excerpts: 6:30-9:05 and 10:00-10:15; note the comments by John Hofmeister, Former President, Shell Oil Co., USA.

CBS News 60 Minutes: “Deepwater Horizon’s Blowout”, aired 22-Aug-2010:
Part 1: 2:25 start, 8:00 end; particular focus on these 3 segments: 3:24-4:37, 4:37-6:01, and 6:01-7:22:
http://www.cbsnews.com/videos/deepwater-horizons-blowout-part-1/
Part 2: 2:40 start, 7:40 end; http://www.cbsnews.com/videos/deepwater-horizons-blowout-part-2/

BBC Production - Documentary: “BP Oil Spill”; Duration 59:07
http://www.youtube.com/watch?v=vWh9jDei-og ; accessed 21-Aug-2014

BBC Production - Documentary: “The BP Oil Spill with Stephen Fry”; Duration 58:58
http://www.youtube.com/watch?v=MCGzCLHAMWI ; accessed 21-Aug-2014

The Technical Causes:
- Damaged Annular on the Blowout Preventer (BOP) – chunks of rubber seal found in drilling mud
- Inoperative Control Pod on the BOP;
- Damaged hydraulic line and weak battery on the BOP
- The BOP could not be activated.
- Pressure test to determine mud and plug integrity was inaccurate.
- Premature removal of mud before plugs were completed and set.

Consider:
What are these systems i.e. engineering controls or administrative controls?

Were these sub-standard conditions or sub-standard practices?

The Latent Cause:
Transocean had attempted to work more cheaply … but who was "driving" them? Who vetoed their path forward? The report stated that "whether purposeful or not, many of the decisions that BP, Halliburton, and Transocean made that increased the risk of the Macondo blowout clearly saved those companies significant time (and money)."

One key facet of this loss incident was the focus on workplace safety. In fact, on the day of the loss incident, BP and Transocean celebrated a safety milestone for operating over 7 years without a serious injury.

Certainly workplace safety is important, however process safety risks associated with the drilling operations and well status were not appropriately considered, evaluated, and managed. Numerous testimonies in the subsequent inquiry indicated that when the pressure was on, process safety was not considered, and thus process safety management suffered. The Transocean Rig was wrapping up operations to seal the well. The decision was to proceed to remove drill pipe and bit, place three concrete plugs, and seal the well. The Transocean Manager wanted to place the plugs with the drill hole full of drilling mud. The BP Manager wanted to remove the mud before the last concrete plug was set because it expedites sealing the well. "Well, my process is different. I think we are going to do it this way." This decision was made despite knowing the deficiencies in the Blowout Preventer.

The appropriate decision should have been to stop. "Stop. Think. Don't do something stupid." Dr. Robert Bea, professor of engineering at The University of California at Berkely, and former chief engineer of Shell Oil. The U.S. White House has asked Dr. Bea to help analyse the BP Deepwater Horizon Oil Spill. Previously, he investigated the Columbia Space Shuttle Disaster for NASA.

Similarly, the loss of focus on process safety while enjoying success on the workplace safety front caused the loss incident at the BP Texas City Refinery.

Reflect on these Questions:
1) Was "safety" a priority or a value?
2) What Risk Management System Elements were weak, weakly applied, or failed?
3) Which of the Key Points from The Engineer's Survival Guide apply?

A Management-Culture Basis for the Cause of the Loss Incident:
"The National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling released a final report on 5 January 2011. The panel found that BP, Halliburton, and Transocean had attempted to work more cheaply and thus helped to trigger the explosion and ensuing leakage. The report stated that "whether purposeful or not, many of the decisions that BP, Halliburton, and Transocean made that increased the risk of the Macondo blowout clearly saved those companies significant time (and money)."

> *<u>Violation</u> of Engineer's Survival Guide, Key Point #3: When you make decisions, put safety ahead of any other objective!*

The report recommends a new approach to risk assessment and management, with regular third party audits of management systems.

Four Key Lessons on Professionalism from the BP-DWH Loss Incident:
When the BP-DWH loss incident is examined opposite benchmarks of professionalism, we can see that although no one wanted nor planned for such an event, the "culture of normalization" within process safety over-rode that chronic sense of unease, even despite a significant management effort and leadership on occupational safety performance. When astutely applied by a leader, the adherence to these key lessons can reset the culture of an organization; perhaps not immediately nor overnight, but the persistent and consistent application of these key lessons can prevent a major loss incident:

1) We have good risk management programs. We must commit ourselves by applying PDCA (planned and tangible actions with meaningful engagement and meaningful outcomes) as demonstrated through real activities (planned inspections, MBWA, and follow-up) to make safety real.

2) When we make safety a value and manage safety as a value, as opposed to managing it as a shifting priority, we shape our organization into the desired safety culture.

3) When we actively analyse for and manage hazards in the workplace, we reduce risk tolerance.

4) Not only must we implement our risk management programs, we must improve our management effectiveness and express that we cannot tolerate any short-cuts on life-saving rules and triggers, critical procedures and work practices.

Description of a Non-incident - Doing it Right:

- In February 2005, Exxon started drilling the Blackbeard West well, 28 miles off the coast of Louisiana, not very far from the Macondo well that led to the Deepwater Horizon event in 2010.
- At the time Blackbeard was the world's deepest oil well: 32,000 feet below the seabed, and potentially had huge reserves, up to 1 billion barrels. Although the prospect looked huge, it was also very risky because of the very high temperatures and pressures in the well.
- By September 2006, 500 days after the start of drilling, the well had reached a depth of 30,067 feet, a record at the time, and was within about 2000 feet of its target. However, well conditions were "hellish", the drillers were experiencing very high temperatures and pressures (more than 29,000 psi / 200 MPa). Indeed, the well had already experienced a “kick” – unexpected back-pressure spike that could result in a blow-out. They were concerned that a blowout could exceed the capacity of the system's BOP.
- In the ensuing discussions as to whether to keep going or not, the chairman and CEO of Exxon, Rex Tillerson, sided with the drillers. That is, he supported their decision to shut down the project and plug the well with concrete. Exxon wrote off Blackbeard as a $187 million dry hole.

Source: http://www/stb07.com/incidents/blackbeard.html , accessed 13-March-2014

The initial estimated BP compensation for the BP Deepwater Horizon Oil Spill is $20 billion! Consider the cost of Blackbeard West as about $200 million, and multiply it by 100 times, to get $20B. Certainly risk management is good business with a factor of 100x savings (or 100x return on investment), even though it was a tough decision to write off the $200M as a dry well with the shareholders.

Compare the impact on PEAP of BP-Macondo Field with the Exxon-Mobil Blackbeard Field.
Chronicle of a Death Forestalled: the Gulf of Mexico oil spill that didn’t happen; Southern Fried Science; February 2005; http://www.southernfriedscience.com/?p=10258 ; accessed 27-Nov-2015

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http://www.nola.com/news/gulf-oil-spill/index.ssf/2010/05/how_the_gulf_of_mexico_oil_spi.html
http://media.nola.com/news_impact/other/oil-cause-050710.pdf, accessed 1-April-2014

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Energy Tribune. The Genesis of the Deepwater Horizon Blowout, Part 2. Phil Rae, 7-Dec-2010. http://www.energytribune.com/50004/the-genesis-of-the-deepwater-horizon-blowout-part-2#sthash.LqGbQM2W.dpbs, accessed 1-April-2014

Case 8: The MMA Train Derailment and Explosion, Lac-Mégantic, Quebec; 6-July-2013:

Introduction:
In the early hours of July 6th, 2013, a runaway train carrying dangerous goods derails in the core of Lac-Mégantic, Quebec. This case study explores the sequence and causes of an entirely-preventable incident that led to a large number of lives lost, infrastructure loss in the centre of town, severely impacted the environment; and the breakdowns in various management system elements that ultimately caused the incident.

Videos:
Lac-Mégantic MMA Train Accident - 6 July 2013; Animation - Sequence of events in the Lac-Mégantic derailment and fire; "On 6 July 2013, a unit train carrying petroleum crude oil operated by Montreal, Maine & Atlantic Railway (MMA) derailed numerous cars in Lac-Mégantic, Quebec, and a fire and explosions ensued.." published by TSB Canada on Aug 19, 2014
https://www.youtube.com/watch?v=wVMNspPc8Zc#t=19; accessed 19-Aug-2014

News Release:

Head of train company in Quebec derailment defends rail line's safety record – CBC News 2013-07-09:
http://www.cbc.ca/news/canada/montreal/story/2013/07/09/burkhardt-train-lac-megantic.html

Head of train company blames rail engineer – CBC News 2013-07-10:
http://www.cbc.ca/news/canada/montreal/story/2013/07/10/lac-megantic-quebec-train-explosion-investigation.html?autoplay=false
In later case studies, you'll have an opportunity to compare the attitude and response of this company leader with those of other major corporations. Do you want to be this kind of leader? Do you want to work for this kind of company?

Focus shifts to accountability in Lac-Mégantic disaster – CBC News 2013-07-13
http://www.cbc.ca/news/story/2013/07/13/montreal-quebec-lac-megantic-train-derailment-accountability-blame.html
What do you think of the approach being taken by the Chair of the Transportation Safety Board?

Lac-Mégantic tragedy made communities 'open their eyes' about rail safety – 2014-07-04
http://www.cbc.ca/news/canada/lac-m%C3%A9gantic-tragedy-made-communities-open-their-eyes-about-rail-safety-1.2695698

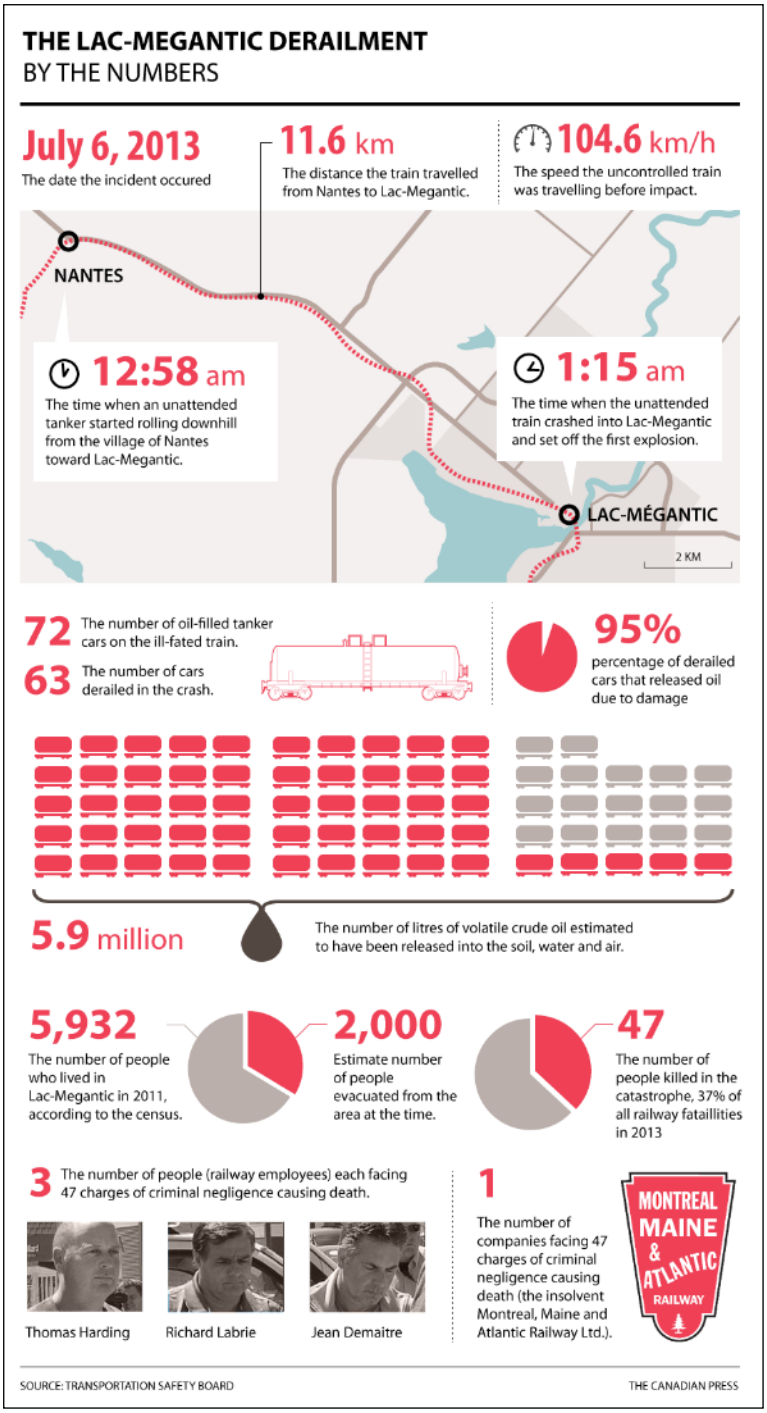
Lac-Mégantic report to be final act for TSB chair Wendy Tadros – CBC News 2014-08-16
http://www.cbc.ca/news/politics/lac-m%C3%A9gantic-report-to-be-final-act-for-tsb-chair-wendy-tadros-1.2735158

Lac-Mégantic needs public inquiry over regulatory failures, says CCPA (Canadian Centre for Policy Alternatives) – CBC News 2014-08-18
http://www.cbc.ca/news/canada/lac-m%C3%A9gantic-needs-public-inquiry-over-regulatory-failures-ccpa-says-1.2737711

Lac-Mégantic: TSB says no single factor to blame for derailment – CBC News 2014-08-19
http://www.cbc.ca/news/canada/montreal/lac-m%C3%A9gantic-tsb-says-no-single-factor-to-blame-for-derailment-1.2739921
" "*The TSB found MMA was a company with a weak safety culture that did not have a functioning safety management system to manage risks,*" the agency said. "

This tragic incident was totally preventable and the responsibility for it rests on senior management.

Lac-Mégantic: By the numbers – CBC News 2014-07-04; accessed 19-August-2014
http://www.cbc.ca/news/canada/montreal/lac-m%C3%A9gantic-by-the-numbers-1.2696398



Transportation Safety Board Canada: Report Lac-Mégantic MMA Train Accident - 6 July 2013; http://www.tsb.gc.ca/eng/rapports-reports/rail/2013/r13d0054/r13d0054.pdf ; accessed 17-June-2016

Case 9: The Role of the Engineer & Lessons from the Nypro Works Explosion, Flixborough UK

Introduction:
The tragic explosion incident at the Nypro Works in Flixborough, UK, is referenced by many safety and risk management practitioners. Even though it was over 40 years ago, its lessons are still with us and clear to see.

This case study demonstrates that Professionalism and Ethics can contribute to good operations or failed operations. It is evident that we need to learn the importance of recognizing and understanding our own limitations, and for involving our peers, stakeholders, and subject-matter experts in the reviews of our changes. Good Management Systems need to be in place to ensure proper reviews of changes such as design changes.

In the DVD, the narrator states that there were three prior incidents involving cyclohexane explosions. One might need to further study the management records to determine if the management at Nypro Works had taken any action to learn from those incidents. Certainly, you will want to ask yourself what lessons did you learn and what lessons will you apply in your careers?

Incidents are a tragedy, but the biggest tragedy is to **not** learn from them.

As with any case study, you should analyse for and be prepared to answer these questions:
- Was "safety" treated or managed as a priority or as a value?
- Which of the Key Points from The Engineer's Survival Guide apply?
- In terms of latent causes, which Risk Management System Elements apply?

Although there are many specific lessons to be learned on several risk management system elements, this case study exemplifies two key personal lessons:
1) **Know your limitations.**
2) **Ask for help!**

Background:

Flixborough, United Kingdom
- Small town in rural England, 258 km (160 miles) north of London.
- Nypro Chemical Plant Location:
- Located on outskirts of Flixborough, 1.2 km (0.8 miles) away.

Plant Products:
- Caprolactam (a base intermediate product for nylon manufacturing) is made by oxidizing cyclohexane liquid in a series of reactors to produce cyclohexanone which is further reacted in a different step to caprolactum (a pre-cursor to Nylon-6)
- World class design of plant, best "safety" features built into design, but poor emergency response capability.

Cyclohexane:
- Highly flammable
- Flashpoint = -20 degC (-4 degF) (flashpoint is the temperature at which enough vapour is evaporated to allow a liquid fuel to burn without assistance).
- Large quantities: 13,500,000 litres (300,000 gallons)
- Batch process involving 6 reactors in series
- Operating conditions = 862 kPa and 154 degC.

Recent Operational History and Events Prior to the Incident:
- In the years prior to this incident, there were reports of cyclohexane explosions in Holland, United States, and United Kingdom (1970: 1 fatality and several severe injuries).
- In the months prior to the incident, there was a cyclohexane leak from Reactor 5. River water (fire water) was poured onto the outside of the vessel to quench and condense the vapours and prevent a fire.
- On March 27, 1974, another cyclohexane leak was detected on Reactor 5: there was a 1" wide crack in steel shell. The plant was shut down, depressurized, and cooled off.
- On March 28, inspection and examination of the reactor showed a 6-ft vertical crack in Reactor 5. Reactor 5 was removed from service for repair.

- Because either there was no spare reactor or the time to install the replacement reactor was of significant duration, the decision was made to install a bypass pipe to connect Reactor 4 to Reactor 6 in order to prevent down-time and production loss.
- The bypass pipe (termed “dog-leg”) was installed, the plant started up, operated successfully for approximately 2 months, and then the disaster struck.

Incident Description:

- Explosion Saturday afternoon 4:53 pm, **June 1, 1974**. Huge vapour cloud of Cyclohexane rose from the plant. The "dog-leg" pipe connection broke releasing the cyclohexane, which was well above its flash-point. The cloud found a source of ignition and resulted in violent explosion.
- Disaster Outcomes: Normally a vapour cloud explosion in open air does not create a strong shock wave. But when there is confinement (in this case tall structures and equipment closely pack together) the energy release in the shock wave increases dramatically.
- Other chemicals stored in plant:
    - 300,000 l (66,000 gallons) Naptha
    - 50,000 l (11,000 gallons) Toluene
    - 118,000 l (26,000 gallons) Benzene
    - 2,000,000 kg (2,000 tonnes) of Anhydrous Ammonia
- 2 bangs: 1st “bang” was small, caused turbulence and mixing; 2nd “bang” happened 30-seconds later, and was extreme.
- One aspect around loss management is community awareness and communications. A good program will see management doing this as part of their job. Nypro had none. The public was very frightened and did not want the company to rebuild. The company did not resume operations.

The Fire:

- There was no plant fire brigade to act as 1st responders, which could have done a lot of good.
- Fire trucks there within 5 minutes from Scunthorpe. In 1/2 hour there were 30 fire trucks
- About as large as largest fire in London Blitz WW2. 250 firefighters had to wear breathing apparatus
- 20,000 people evacuated. 2.5 days to bring fire under control
- Structural steel yields at 520oC (1000oF). This can happen as quickly as within 8 minutes under a direct flame. A hydrocarbon fire is 2200 - 2500oF.
- Still cooling areas 8.5 days after.
- During first 2 days, panic about radioactive release.

Consequences / Impact on PEAP:

- **Killed: 28 (26 were operators inside the control room)**
- **Injured: 100’s, 36 seriously**
- Varying degree of damage to surrounding houses & shops ~2,000 homes
- Total destruction of plant — $48M ($ in 1975)
- Plant replacement value = $180 M in 1975 (today x 20 times that)
- Production and export loss = $120 M; the facility was not rebuilt and never resumed production.
- Litigation, +$60 M.

Problems and The Role of the Engineer:

Regardless of which theory, the One-Event or Two Event, is the case, there is the matter of the dog-leg bypass pipe.

The Problem:

- No qualified mechanical engineer on site.
- Inadequate concern with failure cause.
- Connection between reactors 4 and 6 considered a “routine plumbing job”.
- “Hurry up” attitude of management.

The Report of the Court of Inquiry into this disaster produced no evidence that the company placed production above safety. The personnel involved at this time were the general works (plant) manager, two area managers, the deputy works engineer, and two area engineers. The works engineer, a chartered (registered professional) engineer, had resigned at some time prior to this meeting and had not yet been replaced. Even though the outlet from Reactor 4 was at a different level than the inlet to Reactor 6, the connection was apparently considered a "routine plumbing job." The Court of Inquiry felt that in their desire to accomplish repairs in a hurry, the responsible people were not adequately concerned with the cause of failure in Reactor 5. There was no qualified works engineer with sufficient clout to resist start-up until the cause of failure had been determined. The failure to wait to carry out further examinations was not felt by the Court of Inquiry to be the direct cause of the disaster. The hurry-up attitude was considered to have been an indirect cause of failure as borne out by subsequent events.

More Problems:

- Bellows not designed for thrust.
- Manufacturer: Bellows must be aligned unless pipe adequately supported.
- Design standards for bellows ignored.
- Inadequate vertical and external support.

These bellows were not designed to withstand 38 tons of hydrostatic thrust. In fact, no reference was made to the design guide provided by the manufacturer which specifically stated that the bellows must not be out of line without adequate support for the pipe between them. Laboratory tests after the explosion determined that 38 tons of hydrostatic thrust and the resulting bending moment would cause the pipe to buckle at the miters. No calculations were made at Flixborough to determine whether or not the dog- leg could withstand these forces. Investigation by the Court of Inquiry showed that no reference had been made to the applicable British Standard (BS 3351:1971, ¶ 4.6.2 and ¶ 5.4.2.1) or any other design standard governing the use and installation of bellows-type expansion joints. There was no pressure test of the assembly prior to installation between Reactors 4 and 6.

The Result:

- A Chemical Engineer with only a little experience designed the bypass piping, bellows (expansion joint), and piping support structure.
- He thought he knew enough to do it.
- He thought management expected it of him.
- He did not realize his professional responsibilities.

Discussion Point: Was Safety a Priority or a Value:

Was Safety a Priority or a Value? Why?

The Engineer's Survival Guide:

Which of the Four Key Points would apply? Why?

Resist pressure to resume production without appropriate risk assessments and review of changes. Do not be too anxious to get back into production. In this case, management was too anxious to get back into production: production was higher priority than safety considerations and risk assessments.

Causes:

Immediate Causes Considered at the Beginning

- "One Event Theory": Dogleg bypass lack of support caused bellows to fail - 51 cm (20") diameter. (They used scaffolding to support this large pipe.)
- "Two Event Theory": Small pipe flange 20.3 cm (8") diameter, loose bolts leaked and impinged on pipe - fired off heated pipe causing creep cavitation. Pipe failure, small explosion. This explosion brought down large bypass with great release of gas and major explosion.

Note: The Investigation Team felt that the "One Event Theory" was correct, based on technical evaluation.

Basic Causes:

Engineering and Design Factors:

- Available manufacturers literature on bellows noted only straight connections are safe — was not followed

Job Factors:

- No mechanical engineer (of sufficient calibre) on site staff when bypass designed.
- Senior management previously advertised for mechanical engineer — should have had temporary solution.

Personal Factors:

- A chemical engineer (skilled in production and not design engineering) was in charge of the plant. He completed the "temporary" design for the by-pass. He thought he knew enough about the technical design, and he was driven to satisfy his manager.

Which Management Elements Would Apply to Flixborough?

ENGG404/406 / ENGG406 Risk Management System and its 11 Elements:

1) Management Leadership, Commitment and Accountability.
2) Risk Assessment and Management of Risks.
3) Community Awareness and Emergency Preparedness.
4) Management of Change.

5) Incident Reporting, Investigation, Analysis and Actions.
6) Program Evaluation and Continuous Improvement.
7) Design, Construction and Start-up.
8) Operations and Maintenance.
9) Employee Competency and Training.
10) Contractor Competency and Integration.
11) Operations and Facilities Information and Documentation.

Lesson on Applying Incident Reporting, Investigation, Analysis and Actions: if only this were done pro-actively:
There were several prior failures of a similar nature. If each of these had been investigated, if the technical problems had been thoroughly analysed, if the incidents and investigation / analysis findings had been widely reported and appropriate actions taken, this piping spool might not have failed!

Lesson on Applying Risk Assessment Methods: if only this were done pro-actively:
If a risk assessment were conducted prior to the incident, there would have been at least some peer review of the project, and it might have looked like the semi-quantitative risk assessment as shown in **Section S) below**. This semi-quantitative approach would have uncovered several questions to be answered by management; most certainly, risk-averse management would have engaged subject-matter experts. Other risk assessment tools would develop similar concerns, which is the desirable and necessary action.

Lesson on Applying Management of Change: if only this were done pro-actively:
The application of a rigourous and thorough management of change work process would have driven line management, the people making the decisions, to seek appropriate stakeholder input from subject-matter experts and senior managers within the organization. This work process would have driven all stakeholders to ask those critical questions, thus triggering the application of appropriate risk assessment methods, and the application of appropriate engineering tools. If the bypass piping had been designed with care of original plant, there would have been less likelihood of any problems, and less likelihood of a loss incident. Again, most certainly, risk-averse management would have engaged subject-matter experts.

Lesson on Applying Inherently Safe Design:
Recall **Chapter 5-11: Inherently Safe Designs** i.e. minimization of quantities. If there was less inventory of cyclohexane in the system, the incident would have been less severe.

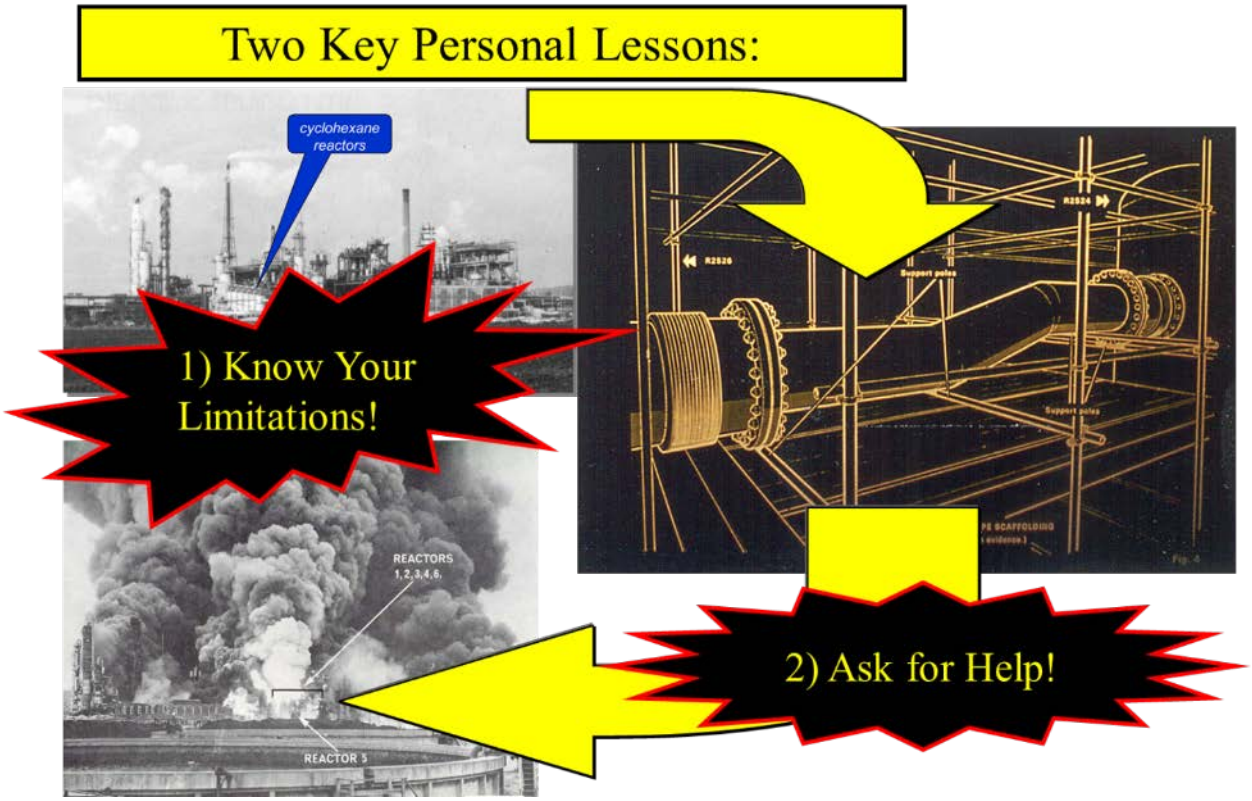
Lesson on Applying AB OH&S Code Part3, A Current Perspective:
- In hindsight, the bellows on the by-pass, and the by-pass itself, was not built in accordance with manufacturer's specifications or specifications certified by a professional engineer.
- Current Alberta OH&S Code Part 3 Specifications and Certifications states (paraphrased) that *"an employer must ensure that equipment and supplies are erected, installed, … in accordance with the manufacturer's specifications or the specifications certified by a professional engineer…"*
- Part 3 is relatively new, came into force in May 1, 2004, and will play more and more of an enforcement role in Alberta industries. From the perspective of government, Part 3 requirements are one of the first layers in the "Swiss Cheese Model". Recall "due diligence"? Meeting requirements of Part 3 satisfies due diligence.

Lessons Learned Through-out the Petrochemical Industry:
- This was a "wake-up call" for the petrochemical manufacturing, storage, distribution, and transportation industries. For the first time, a government (the UK Government) announced that it was going to hold a public inquiry (a very powerful form of governance in a country) into the event. Prior to this event, governments had taken a "hands off" approach because industries insisted that everything was under control.
- Conduct hazard identification and risk assessments!
- Check plant site lay-out and provide appropriate spacing for hazardous processes and chemicals.
- Minimize inventories (storage or "in process") of flammable and toxic chemicals.
- Always follow pertinent design codes and legislative requirements.
- Ensure robust emergency preparedness and emergency planning.
- Consider location of control rooms: explosion-proof or locate remotely.
- Ensure that training for decision makers is mandatory.
- Redesign and re-start must meet same standards as original design.

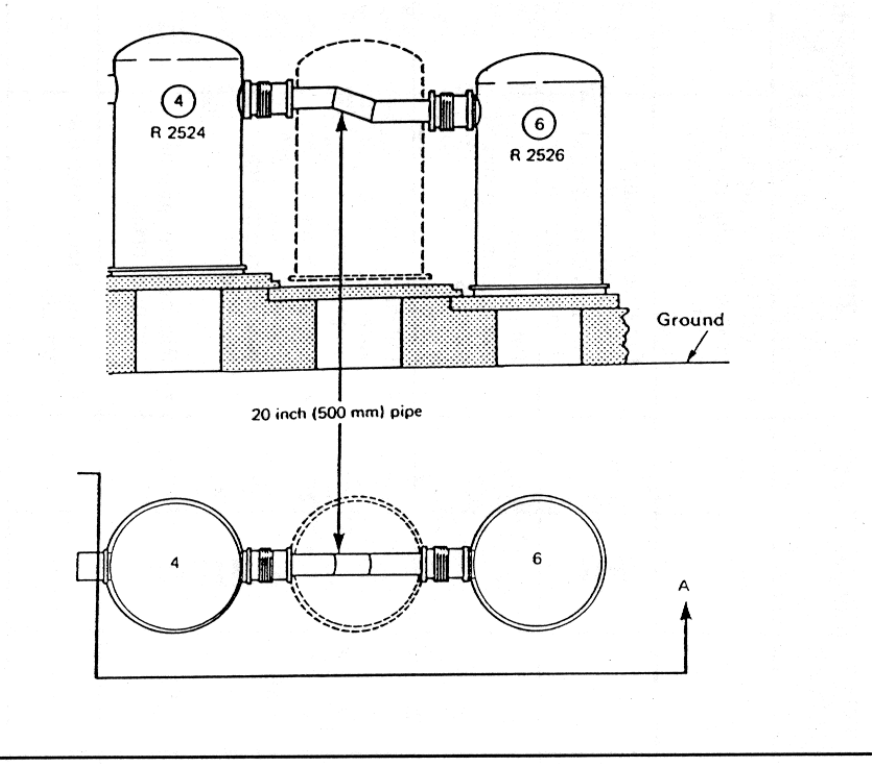
Two Key Personal Lessons:
There are two key lessons for you personally:

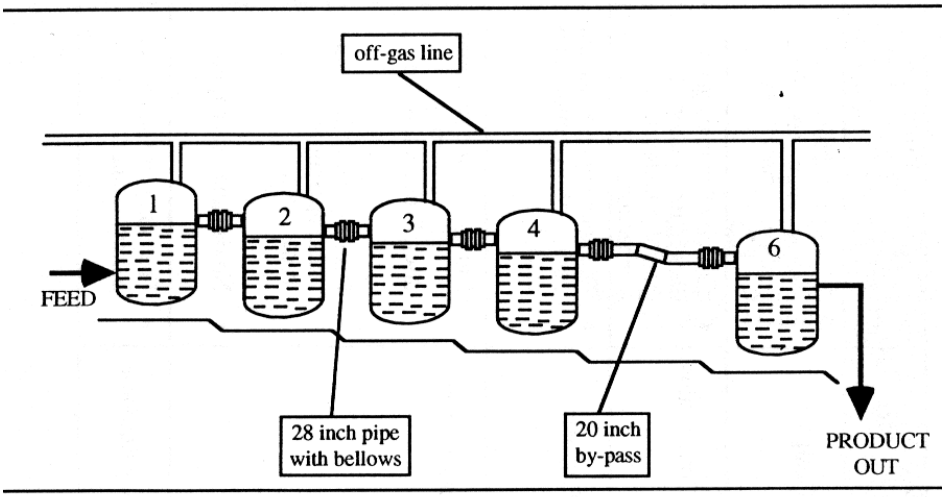
Know your limitations!
Understand what your field of expertise is, your limitations within that field, and recognize when you are practicing (your project assignment and/or design requirements) beyond your limitations or outside your capabilities i.e. know when you are incompetent to perform. Of course, you should learn and gain knowledge and expertise while working under direction of a competent person; that is how you gain expertise. Each discipline should know their limits within their field of expertise and competency.

Ask for help!
Sometimes asking for help is difficult for a variety of reasons: the safety culture; don't want to appear that you don't know your job, etc. You need to realize that in operations, installations, and facilities where risk management is key to preventing incidents that asking for help is the best action you can take. It's okay when you don't know or are not capable of performing the work requested of you. No one is an expert in everything! Say "I don't know" and ask for help. We can and must engage and work with subject-matter experts when undertaking work outside our field of expertise. Consult in teams, especially at redesign, and with original designers / design contractor Again, this is how you build expertise while working under direction of a competent person.



A) Flixborough Reactor Diagrams:

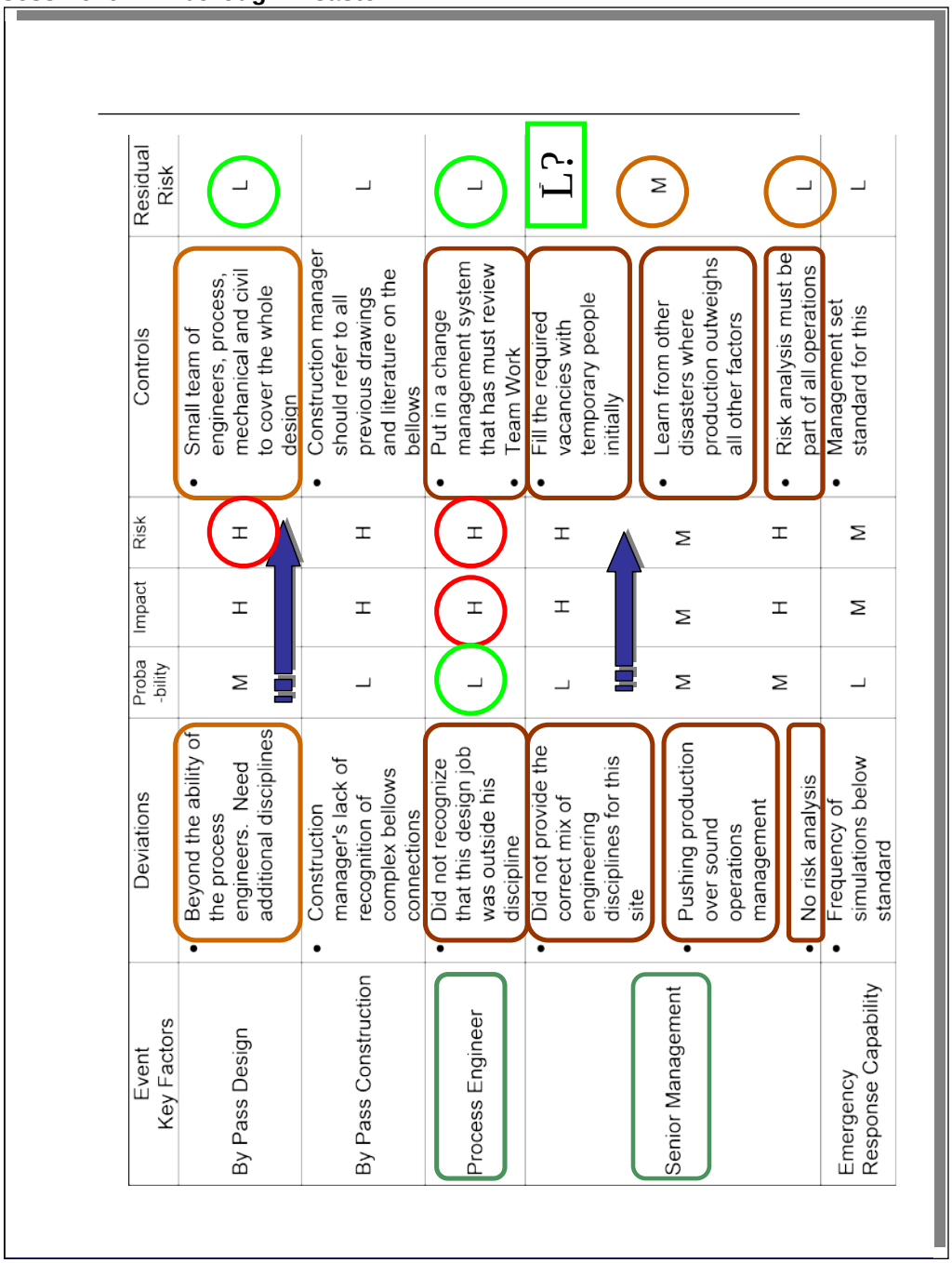




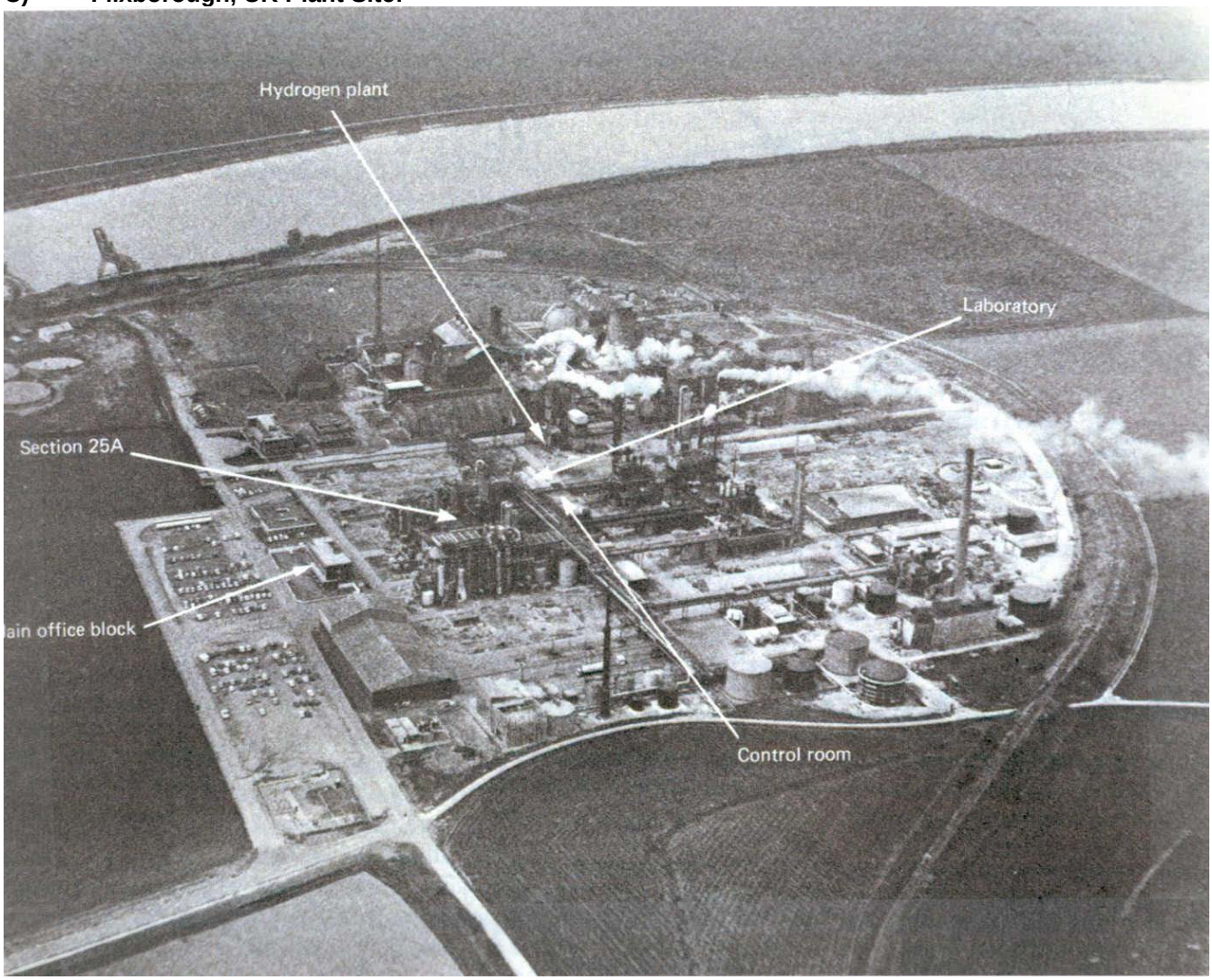
B) Risk Assessment - Flixborough Disaster – If only this were Pro-active:

Event Key Factors	Deviations	Proba -bility	Impact	Risk	Controls	Residual Risk
By Pass Design	• Beyond the ability of the process engineers. Need additional disciplines	M	H	H	• Small team of engineers, process, mechanical and civil to cover the whole design	L
By Pass Construction	• Construction manager's lack of recognition of complex bellows connections	L	H	H	• Construction manager should refer to all previous drawings and literature on the bellows	L
Process Engineer	• Did not recognize that this design job was outside his discipline	L	H	H	• Put in a change management system that has must review • Team Work	L
Senior Management	• Did not provide the correct mix of engineering disciplines for this site	L	H	M	• Fill the required vacancies with temporary people initially	-
	• Pushing production over sound operations management	M	M	M	• Learn from other disasters where production outweighs all other factors	M
	• No risk analysis	M	H	H	• Risk analysis must be part of all operations	L
Emergency Response Capability	• Frequency of simulations below standard	L	M	M	• Management set standard for this	L

Risk Assessment - Flixborough Disaster:



C) Flixborough, UK Plant Site:



D) References:

Health and Safety Executive, The United Kingdom, Flixborough (Nypro UK) Explosion 1-June-1974: http://www.hse.gov.uk/comah/sragtech/caseflixboroug74.htm Accessed on 23-Aug-2013

New Zealand Safety Council, Flixborough UK Study; Accessed on 23-Aug-2013 http://safetycouncil.org.nz/index.php?option=com_content&view=article&id=76&Itemid=90

Wikipedia Flixborough Disaster, 1-June-1974: Accessed on 23-Aug-2013 http://en.wikipedia.org/wiki/Flixborough_disaster

Case 10: Lessons from STS-51L Challenger 1986-01-28 & STS-107 Columbia 2003-02-01

STS-51L Challenger Incident 1986-01-28
DVD Video: "The Challenger Disaster", Educational Communications Center, Binghamton, State University of New York; start at 0:00 and end at 6:15.
Pause at 02:01: listen to the upcoming dialogue (at 02:10) between the flight director, Gene Kranz, and the flight controllers, especially the flight director's closing words, "CAPCOM, we are "GO" for landing" for Eagle, Apollo 11, July 20, 1969.
Pause at 03:45: listen to the upcoming voice-over of Professor Mark Maier, "… because we could have stopped it, we had initially stopped it, and then that decision was made to go forward anyway."

Video: MSNBC: Challenger Beyond The Tragedy,
https://www.youtube.com/watch?v=JMGQad4ik5I accessed 21-Aug-2014

ABC News 20-20 6-3-1986 Countdown to Disaster; Video: 1) 3:55-5:50; 2) 10:30-12:38
http://www.youtube.com/watch?v=KdXkT-mxJJs accessed 29-Oct-2014

The comparison of NASA's APOLLO Space Program with their Space Transportation System (STS) Program could be summarized in the phrase "GO / NO GO". For Apollo, everything was proven "right" before taking the next major step in the mission e.g. launch, landing, etc., versus the STS program where the engineers had to prove that something was wrong in order to delay or abort the next major step.

Incident Description:
STS Challenger fuel tank exploded during in-flight throttle-up, post-launch; loss of **7 highly trained and skilled astronauts**, STS Challenger, all stowed equipment, and the planned scientific research work.

Short-term Losses Incurred:
Loss of life - 7 astronauts
Destruction of Shuttle (US$2.8 billion, 1986).
Emotional stress to those involved in project.
Recovery costs (US$5 million).

Long-term Losses Incurred:
Lawsuits and insurance premiums.
Decreased funding from industry due to lack of faith in shuttle program.
Postponement and eventual cancellation of three shuttle flights resulted in loss of income, loss of reputation, reduced productivity and efficiency.
Loss of morale. Dissension in the ranks.
It helped open the door to private enterprise and other governments as alternative suppliers for transport to space.

Immediate Causes:
Evening prior to flight, the temperature was 15 Fdeg colder then previous flights.
Pre-flight leak tests caused more damage by puncturing O-ring seal.
Rubber O-ring seal failed, burned away, and cuased solid rocket combustion gases to escape and impinge on the LOx and H2 rocket tanks.
Rocket tanks failed, oxygen and hydrogen leaked, ignited, and exploded.

Latent Causes:
Recommendations made by engineering firms to NASA were overridden.
NASA did not learn from previous incidents when O-rings failed that were operated beyond the recommended temperature limits i.e. "if one of the seals leaks a little and the flight was successful, the problem isn't so serious."
There was a large amount of pressure put on NASA to get the job done fast. Industry pressure because of fear of losing contracts and government pressure because of fear of going over budget.
Technical recommendations not heeded.
Inadequate quality control procedures for determining O-ring quality; overall, there were 18,000 fewer inspections done on the Challenger versus other missions.
Many employees had to work overtime due to the pressure from management (fatigue errors).
Lack of communication among employees.

Sticking to their timetable for take-off took precedence over safety. Production a priority over safety.
Management pressure on cost & schedule
Timetable priority over safety.
Fewer inspections done.
Failure to investigate previous incidents.
Failure to do / follow a risk assessment.

Details of the O-Ring:

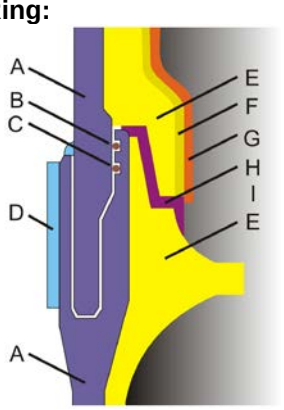
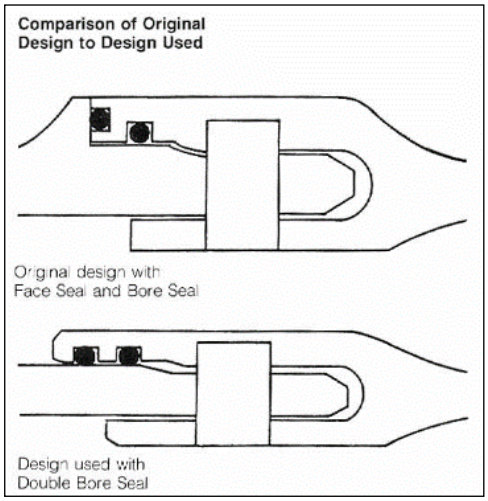


Diagram showing a simplified cross-section of the field joints between the segments of the pre-Challenger Space Shuttle Solid Rocket Boosters.

A - steel wall thickness 12.7 mm
B - base O-ring gasket
C - backup O-ring gasket
D - Strengthening-Cover band
E - insulation
F - insulation
G - carpeting
H - sealing paste
I - fixed propellant

The O-Ring fails, causes solid rocket booster hot gas blow-through; impinges on Liquid H2 Tank; H2 Tank explodes, ruptures Liquid O2 Tank; mixture of H2 and O2 causes massive explosion that destroys STS-51L

O-Ring Design Change:



One More Piece of Information … O-Ring Data:

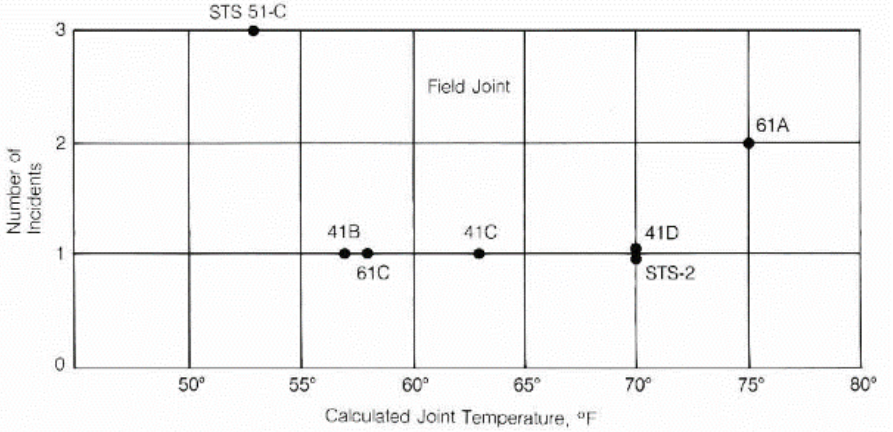


Figure 6
Plot of flights with incidents of O-ring thermal distress as function of temperature

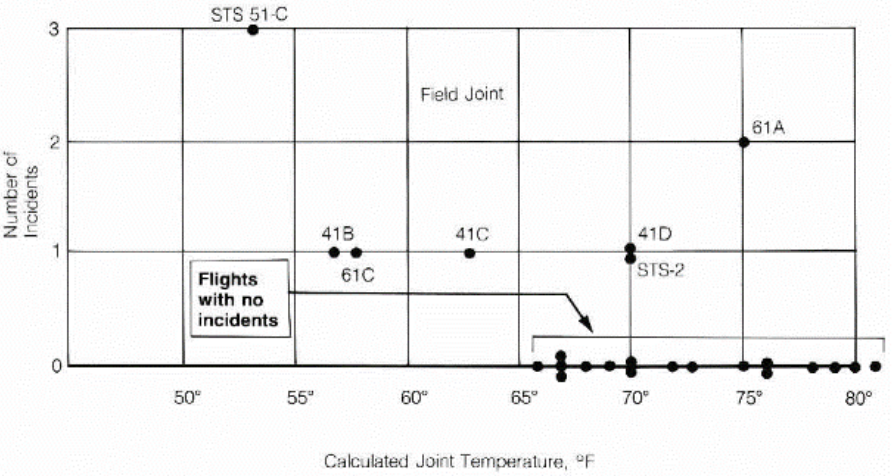


Figure 7
Plot of flights with and without incidents of O-ring thermal distress

NOTE: Thermal distress defined as O-ring erosion, blow-by, or excessive heating

Compare the two graphs above. From the data in Figure 6, one could conclude (and did, either erroneously or by presenting the data in a form to support only one conclusion) that the cold temperatures lead to O-ring failures but that these O-ring failures are "survivable" – there was no catastrophic failure. However, one concludes from Figure 7 that at temperatures below 65 degF there are ALWAYS O-ring failures, and that chance is the sole factor in the risk equation of catastrophic failure.

Recommendations from the Incident Investigation (Roger's Commission):

"The Commission found that the O-rings were at fault, but poor management was also to be blamed." Video segment 07:13 - 07:19

Design:
Improve design of O-ring
Replace type of putty used
Solid, 1 piece rocket booster

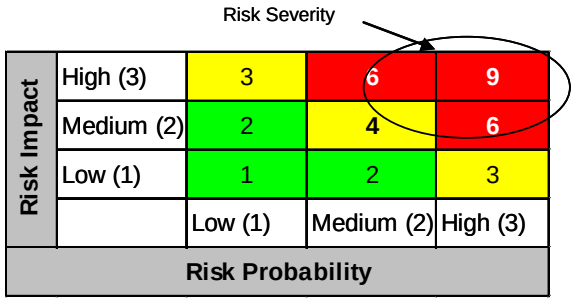
Escape pod / mechanism for escape during first two minutes of launch

Operating Procedures:
Stringent rules for launch conditions (i.e. Temperature conditions)
Non-destructive testing techniques for leaks
Emphasis on safety and procedures
Report ALL incidents
Strict training programs

Management: Proactive and Reactive
Reduce number of flights per year
Management and technical co-operation
Technical override
On-line computer system for communication
Political liaison as honorary member of management team
Alter risk acceptance level
Safety & Loss Management program
Risk Assessment for each flight

Risk Assessment (attached)
A copy of some excerpts for the Challenger Risk Assessment follow below.
An initial risk assessment is done: the risk of the deviation is quantified using guidelines, per examples of the generic risk matrix and the "NASA Probability Guidelines". This is documented as "Risk" of the deviation as shown in the Risk Assessment Tables.
After controls are developed and implemented, another risk assessment is done to determine the residual risk of the deviation with controls in place. This is documented as "Residual Risk" of the deviation with controls in place, as shown in the Risk Assessment Tables.

Risk Matrix:



NASA Probability Guidelines:

Low (1)	The event probably will not happen OR Historical evidence, including lessons learned, suggests this to be an unlikely occurrence OR Has not happened in other organizations of similar size.
Medium (2)	The event has a reasonable likelihood of occurrence OR Historical evidence, including lessons learned, suggests this sometimes occurs.
High (3)	This event is very likely to occur OR Historical evidence, including lessons learned, suggests this to be a very likely occurrence OR Has happened in other organizations of similar size

NASA Consequence Guidelines:

Low (1)	Impact limited to task or activity OR

	Project budget overruns can be fully covered by partial use of Project funding reserves
Medium (2)	Project budget overruns can be fully covered by full use of available Project funding reserves
High (3)	Project budget overruns or other negative budget events impact program funding available for pending chapters; causing a delay in initiating new chapters and/or eliminating planned chapters.

Although these two tables may look simplistic, in reality, there is a vast amount of research, science, and engineering behind these guidelines.

Is it interesting to note that the consequences are based on budgets? It would seem the safety of the astronauts was not a consideration in this analysis.

Risk Assessment for STS Challenger - Procedures:
Risk can be semi-quantified given the risk criteria above. Note that this SQRA was completed post-incident.

Event Key Factors	Deviations	Prob-ability	Impact	Initial Risk	Controls	Residual Risk
Procedures	- launch in cold weather does not allow O-rings to seal properly	H	H	H	- do not launch in cold weather	L
	- unclear procedures regarding environmental factors	L	H	M	- have clear non-negotiable procedures	M
	- leak check procedures cause penetration of the putty and loss of thermal barrier	H	H	H	- do not puncture putty when checking for leaks	M
	- pressure to keep on schedule	H	H	H	- emphasis on safety and procedures	M
	- lack of incident reporting (i.e. 147 incidents in 1 yr. with 56.5% due to human error)	M	H	H	- encourage reporting of all incidents	M
	- training programs inadequate for Aerospace personnel	M	M	M	- strict training programs for everyone	L

Risk Assessment for STS Challenger – Management Aspects:
Risk can be semi-quantified given the risk criteria above. Note that this SQRA was completed post-incident.

Event Key Factors	Deviations	Prob-ability	Impact	Initial Risk	Controls	Residual Risk
Management	- pressure to keep on schedule	H	H	H	- reduce number of flights per year	L
	- management not listening to engineers	H	H	H	**-** management / technical cooperation - technical override	L
	- refusal to change O-ring configuration	H	H	H	- change O-ring configuration	L
	- poor communication due to information filtering at lower levels`	H	H	H	- launch made by technically experienced group	M

					with computer on-line system	
	- poor internal communication between management and engineers	H	H	H	- technical managers on staff	M
	- altering of criteria for scheduled maintenance	H	H	H	- stringent control of safety measures over the constraints	M
	- political pressure / media pressure overriding common sense of managers	H	H	H	technical override of all launch decisions - have a political liaison as an honorary member of the management team	L
	- risk acceptance level inadequate (ie. millions spent on emergency landing procedures with no escape in the first two minutes of flight)	H	H	H	- a proper risk management process with clearly defined levels of acceptable risk that are supported by everyone involved.	L

STS-107 Columbia Incident 2003-02-01
Video: PBS Nova Documentary S36E02 “Columbia Space Shuttle Disaster”;
https://www.youtube.com/watch?v=gd0hBBGjLlM accessed 21-Aug-2014

Incident Description: STS Columbia disintegrated in-flight during re-entry at 10,000 mph, after 16 days in orbit, post-mission. Seven highly skilled astronauts were killed.

Losses Incurred, Immediate and Long-term:
All 7 astronauts are killed
$4 billion (2003) spacecraft is destroyed
Debris scattered over 2000 square miles of Texas; large clean-up cost
NASA grounds shuttle fleet for 2-1/2 years

Immediate Causes:
A foam insulation piece fell off the Columbia fuel tank on liftoff.
The foam piece struck a high-temperature ceramic insulation tile on the leading edge of the wing.
The impact broke off or cracked open the ceramic insulation tile.
During re-entry, hot gas (plasma) entered the interior chamber of the wing, ultimately breeching the hull of the space craft.

Latent Causes:
Hazard identification and near miss events from previous flight incidents were not followed up on.
Reports of previous strikes were not considered a failure of the tank insulation, but a success of the robustness of the leading edge of the wing.
NASA never learned from previous mistakes, i.e. “Challenger incident required thorough risk assessments”
Inadequate quality control procedures for determining tile quality

Comments?
What has changed at NASA?
Complacency?
Priorities?

A Summary Comparison of STS 51L Challenger and STS-107 Columbia

The technical failures that caused the losses of STS Challenger and STS Columbia have been well-studied and are easily grasped within most fields of engineering, if not all. Our intent in studying these loss incidents is more than just understanding the technical causes. Our intent is to draw out one key lessons in managing any organization:
Be vigilant about and take action to arrest the normalization of deviation.

This is akin to the Key Point #4 of the Engineer's Survival Guide:
Pay attention to failures in safety systems and take action!

A Retrospective Report on Challenger and Columbia – The New York Times
For the lecture on this chapter, it is beneficial to review the video. Although there are many, many videos, books, and presentations on Challenger and/or Columbia, one of the best that combines both the technical causes and the key lesson is the New York Times Retro Report.

Four key persons are interviewed:
Mike Mulloy, NASA Project Manager for the Solid Rocket Boosters at the time of the Challenger incident.
Allan J. McDonald, Senior Engineering Executive, Morton-Thiokol, at the time of the Challenger incident. Morton-Thiokol was the designer and manufacturer of the solid rocket boosters.
Rodney Rocha, NASA Engineer, at the time of the Columbia Incident.
Diane Vaughan, investigator and author of "The Challenger Launch Decision", undertaken and completed years after the incident. Independent of NASA and Morton-Thiokol.

Although you can view the entire 20 minutes of the video, as a minimum, please view the key time snips (~10 minutes) as highlighted in the first table, or listed in the second table below.

https://www.youtube.com/watch?v=-O_DMyHdq_M
New York Times – RetroReport: Space Shuttle Challenger Disaster: Major Malfunction; Published on Jun 2, 2014; On Jan. 28, 1986, seven astronauts "slipped the surly bonds of earth to touch the face of God." America's space program was never the same. Filename **NYTimes Doc Challenger RetroReport hhmmss 002014**

Time Snip	Content
00:00-01:55	The Challenger Loss Incident, 1986
01:55-05:40	GO or NO GO: The Challenger Legacy: The Apollo Space Program and the era of the "Can Do" attitude and innovation; The complex technology of the Shuttle; The Design: 03:00 – 03:30 The Funding Model for the STS Program; The challenges of re-usable space technology; NASA worked with private contractors (for-profit enterprises); The ambitions of the NASA organization; Under constant pressure: the expectations set by NASA management and the US Government.
05:40-06:42	O-Ring Anomalies: 06:35 - Dianne Vaughan: "It didn't seem so terrible to continually expanded the bounds of acceptable risk"
06:43-09:02	The 10th Challenger Launch and low temperatures (18 degrees Fahrenheit, -8 degC) The role of the contractor; Overnight record-breaking low temperatures; Concern about the O-rings ability to seal; NASA pressure opposing launch delay.
09:03-11:43	The Engineers' Decision: Engineers recommended to delay the launch; The Manager's Decision: reversal of the engineering recommendation; NASA management pressured Morton-Thiokol management; 10:57: Larry Mulloy: "… rationalizing this erosion since the second flight"; 11:07: Dianne Vaughan: the decision to launch was "organizationally supported"; 11:26: Allan J. McDonald: "refused to sign" … "too much risk to take"; Senior management at Morton-Thiokol "signed off".
11:44-12:08	The Presidential (Roger's) Commission Report Cold (temperature) and joint design were major factors; Squarely pointed a finger at NASA managers; Recognized that there was pressure to launch; Vaughan questioned whether the cause was simply pressure "to launch enacted by amorally calculating managers".
12:09-13:06	Diane Vaughan found something completely different: "No one wanted this to happen"; "They applied all the usual rules in a situation where the usual rules didn't apply"; "The real crux … how do you get people to recognize you need to do something different than what you've been trained to do?" Presidential Commission: Prompted many changes but nothing about the need to change the organization, nor how to change the organization

Time Snip	Content
13:31-15:30	The preamble to STS Columbia, 2003: 13:55: large piece of foam hit the left wing and decision to ask for more data; previous strikes on previous flights without catastrophe; requests for more data were denied; foam strikes were not considered a flight risk and NASA management did not want to change Columbia's mission;
15:31-16:35	The preamble to STS Columbia, 2003: The decision by Linda Ham; look for the captioned quotes of her directive. Ham received three different requests for satellite imaging, "… and they were all putdown (denied) for different reasons. The similarity between Challenger and Columbia was the falling back on routine under uncertain circumstances," Diane Vaughan. "… there is absolutely no concern for entry" into the atmosphere.
16:36-17:58	The Columbia disaster on re-entry. "Part of our engineering culture is that we should always work to the chain of command", and this was a mistake. "The anomalous data (the foam strikes on the leading edge of the left wing) confirmed my worst fear."
17:59-20:14	The Columbia Accident Investigation Board: After Columbia, Vaughan worked closely with the CAIB; Concluded that NASA had ineffective leadership and a flawed safety culture; Admiral H. Gehman: "We are quite convinced that these organizational matters are just as important as the foam." 18:26 - "This happens in many different kinds of organizations. I don't think that the general public got the position of either Larry Mulloy or Linda Ham. And that their behaviour was to a great deal determined by working in a very rule-oriented organization." 19:28 - Diane Vaughan: "We can never resolve the problem of complexity, but you have to be sensitive to your organization and how it works. While a lot of us work in complex organizations, we don't really realize the way the organizations that we inhabit, completely inhabit us."

Excerpted List of Video Snips for the In-class Lecture:

Time Snip	Content
05:40-06:42	O-Ring Anomalies: 06:35 - Dianne Vaughan: "It didn't seem so terrible to continually expanded the bounds of acceptable risk"
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Relevance of Recommendations to the ESRM Program:

When we write recommendations we need to connect them to one or more of the Risk Management Elements we use to manage the risk once we accept it. For the Challenger which of the eleven elements in our course apply to the tragedies of STS Challenge and to STS Columbia?

Relevance of Recommendations to the Engineer's Survival Guide:

Which one (or more) of the guiding principles in The Engineer's Survival Guide apply to the tragedies of STS Challenge and to STS Columbia?

Complacency in the Workplace:

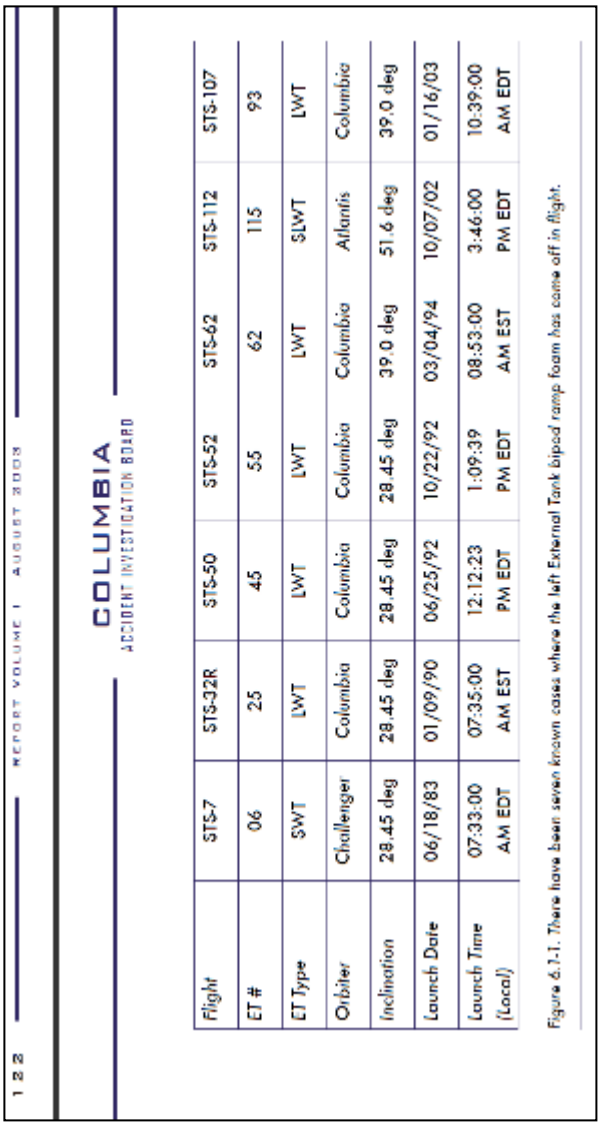
We often hear about persons who were injured on the job, and when asked why they put themselves at risk, they responded "I always did it this way" or "I lost focus" or "I was distracted." In a way, the person became complacent about their work, not so much that they were unconcerned about hazards, but had put the hazards at the back of their minds because they had been successful so many times in performing their jobs, and each little short-cut or inattention to detail or acceptance of a substandard condition in a tool or material or their tasks (the "normalization of deviance") moved them into a state of "individual complacency."

Can an organization become complacent? How do you think an organization becomes complacent? In the two Shuttle Disasters we're learning about in this lecture, do you sense that the organization is becoming complacent? Where an organization has broadly allowed the "normalization of deviance" to ultimately adversely affect operations, it is a result of complacency pervasive throughout the organization.

Summary:

We have the ability to do excellent designs. However, each and every design has limitations that need to be heeded.
We must recognize our professional duty to society at all times. Professional ethics cannot be compromised.
Management has the right, and responsibility, to make decisions with overall success in mind.
Conflicts of interest will be around us constantly and our awareness of these is key.
Management systems consider the situations when conflicts arise, so as to ensure that conflicts are risk-managed (and not solely budget-managed or schedule-managed), and that the appropriate and informed risk-based decisions are made.
We cannot set up situations that can lead to failure.

Near Miss Events: Foam Strikes on the Leading Edge During Launches:



122 REPORT VOLUME I AUGUST 2003

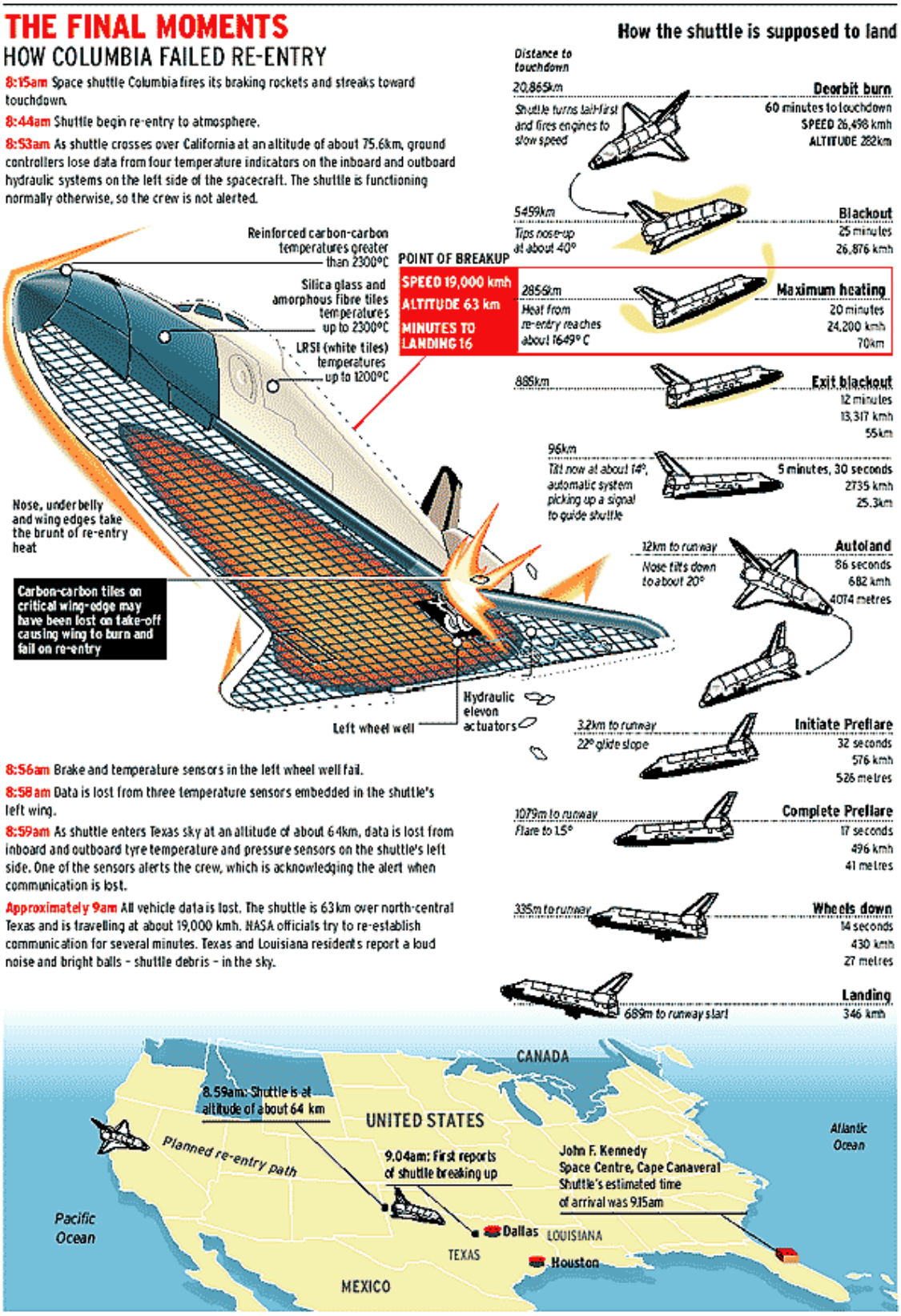
COLUMBIA
ACCIDENT INVESTIGATION BOARD

Flight	STS-7	STS-32R	STS-50	STS-52	STS-62	STS-112	STS-107
ET #	06	25	45	55	62	115	93
ET Type	SWT	LWT	LWT	LWT	LWT	SLWT	LWT
Orbiter	Challenger	Columbia	Columbia	Columbia	Columbia	Atlantis	Columbia
Inclination	28.45 deg	28.45 deg	28.45 deg	28.45 deg	39.0 deg	51.6 deg	39.0 deg
Launch Date	06/18/83	01/09/90	06/25/92	10/22/92	03/04/94	10/07/02	01/16/03
Launch Time (Local)	07:33:00 AM EDT	07:35:00 AM EST	12:12:23 PM EDT	1:09:39 PM EDT	08:53:00 AM EST	3:46:00 PM EDT	10:39:00 AM EDT

Figure 6.1-1. There have been seven known cases where the left External Tank bipod ramp foam has come off in flight.

ET: External Tank Number (the external tank was jettisoned and not recovered after launch)
ET Types: SWT = Standard Weight Tank; LWT – Lightweight Tank; SLWT = Super Lightweight Tank

How STS Columbia Failed on Re-entry:



Lessons from Challenger: Six Key Organization Culture Themes by Mike Mullane:
The tragedy of STS Challenger was thoroughly investigated by NASA as well as other experts in the field. Mike Mullane, at the time an astronaut within the NASA space program, investigated this incident and extracted six key organization culture themes from these reports, as summarized immediately below and further in the Mullane's notes and training information. The six key themes:

Maintain Sense Of Vulnerability: Since catastrophic accidents involving hazardous materials or activities are not very common, most organizations never have the unfortunate opportunity to experience one. This can create a false sense of security and decreased operating discipline, which can dull management system effectiveness. Lapses in critical prevention systems can result.

Combat Normalization of Deviance: When established engineering or operational constraints are consciously violated, without any resulting negative consequences, an organizational mindset is encouraged that more easily sanctions future violations. Such violations are more likely to lead to a serious accident.

Establish an Imperative for Safety: This addresses a range of considerations, from showing visible support for safety through management actions, statements and priorities to soliciting and welcoming differing opinions on critical safety issues.

Perform Valid/Timely Hazard/Risk Assessments: Without a complete understanding of risks, and the options available to mitigate them, management is hampered in making effective decisions. Perfunctory assessments lead to flawed decisions.

Ensure Open and Frank Communications: Information must effectively flow both up and down the organization, and laterally between functional groups within the organization. "Bad news filters," emphasis on "chain of command" communications, and "silo" mentalities can stifle the exchange of safety-critical information.

Learn and Advance the Culture: We must be open to learning from our mistakes (and those of others), and to making the necessary corrections … or we will repeat those mistakes.

Case 11: Environmental Challenges

In the News: Lake Wabamun – 3-August-2005:
On August 3, 2005, 43 cars of a CN Rail train derailed on the north shore of Wabamun Lake, about 23 kilometers east of the Village of Wabamun. The derailment caused the breach of many rail-cars, spilling their contents of more than 700,000 litres of Bunker C oil and 88,000 litres of pole treating oils onto the immediate area and subsequently flowing into the lake. Although there were no injuries, there was an indeterminate kill of aquatic life. Private property was damaged as well as the railway assets (rails, rail-bed, rail-cars) and the customers' products. The rail-line was out of service for several days. Ultimately, over $130 million in compensation and $1.4 million in fines were paid out. Risk management applies even in transportation.

<table>
<tr>
<td colspan="2">  </td>
<td>So what does an environmental incident add up to?

Lost assets.
Lost business.
Legal liability.
Lost of reputation.
And much more.</td>
</tr>
<tr>
<td colspan="2">CN Rail at Lake Wabamun, Alberta August 3, 2005:
➢ No fatalities, no injuries; indeterminate aquatic life kill
➢ Almost 800,000 litres of heavy oils spilled into the lake
➢ 43 rail-cars, rail-bed, locomotives, several local properties, contents of the rail-cars
➢ $140 million in costs; rail-line out of service for several days, interruptions to supply customers</td>
<td>MMA Rail at Lac Megantic, Quebec – July 6, 2013
➢ 47 fatalities, 5 missing, over 2,000 evacuated
➢ Over 8 million litres of petroleum crude oil, significantly diluted with lighter ends, were spilled and caught fire, about 100,000 litres escaped to the near-by river; heavy smoke emitted and dispersed into the broader environment
➢ 72 rail-cars, rail-bed, car contents, over 30 buildings destroyed, hundreds damaged, water supply contaminated
➢ Estimated clean-up costs and compensation may be several hundreds of millions of dollars; rail-way may be forced out of business</td>
</tr>
</table>

In the News: Lac Megantic, Quebec – July 6, 2013:

The Issues Associated with Modern, Industrial Human Activity:

With any industrial endeavour, questions are raised about the benefits and drawbacks about industrial human activity, and more questions. Consider pipeline versus rail-way for transportation of non-renewable oil and gas resources and the environmental impact, the safety of the means, and the energy efficiency:

- Impact during construction and during operation.
- Disruption of natural habitat for all wildlife: migratory paths for large land mammals or wetlands for birds or natural waterways for aquatic species.
- Risk of leaks and spills: probabilities, consequences / impact on the environment.
- Risks associated with the sea-going activities: loading, shipping lanes, collisions, leaks, spills, and clean-up; pollution from shipping operations; disruption of sea-life; at both ports of origin and at destination.
- Environmental impact of the consumption of the hydrocarbons by the consumer / end-user: emission of carbon dioxide and other products of combustion, etc.
- Environmental impact of the consumption of energy for the transportation of the hydrocarbons.

Are "Green Solutions" Really the Answer?

Consider the electrically-powered vehicle to replace the internal combustion engine. Consider the full life-cycle of the materials used to manufacture vehicle. Consider the sources of energy consumed to manufacture those materials. Consider the sources of energy consumed to fuel the electric vehicle i.e. recharge the batteries. Consider the disposition of the materials at the end of life of the vehicle.

Consider wind-powered wind-mill generating stations to replace other types of electricity generating stations. Consider the full life-cycle of the materials used to manufacture the wind-mill. Consider the sources of energy consumed to manufacture those materials. Consider the sources of energy consumed to fuel the wind-mill i.e. wind. Consider the disposition of the materials at the end of life of the wind-mill.

Environmental Priorities:

Do we know where our environmental priorities lie? Do we really know what is at stake? What is the most important project to work on? Which one of these should it be?

- Excessive emissions of pollutants (CO_2, acid gases, heavy metals, particulates, green-house gases, etc.) to the global atmosphere from non-regulated sources and sources without air-pollution control process equipment (scrubbers)?
- Global warming? Increase in ocean temperatures? Increase in severity of weather?
- Clean water? Contamination of surface waters, ground water, and aquifers. Excessive and unbalanced consumption of aquifer waters?
- Ozone layer protection?

- Health of bees? Food supplies? Consumption of non-renewable fertilizers (potash)?
- Deforestation? Mono-agriculture? Genetically-modified foods and crops?
- Dirty oil? (Exactly what is "dirty oil" anyway?) Depletion of fossil fuels? Biofuels?
- Wastes from spent nuclear fuels, and processing radioactive materials?
- Spills and leaks to the environment?
- Mountain forest pine beetle? Which of numerous invasive species?
- US-EPA "Superfund" sites?
- Others?

With finite resources, we can only manage so much. Consider these questions:

- Should priorities be on preserving non-renewable resources through reduced consumption?
- Or should the priorities be on researching and developing new technologies such that societies are less dependent on non-renewables?
- Or on securing the food chain and potable water sources?
- Or on cleaning up the legacy contamination of our land and water-ways?

Environmental Challenges:
The list of issues and these questions are intended to demonstrate how broad the topic of "environmental impacts is, and why the environment is and must be included in risk management. The consequences of the activities undertaken by industries, indeed all of humanity, cannot be undone. The clock cannot be turned back. Certainly, these issues must be tackled, but our challenge is that our efforts must be focused in two directions:

- One looking back to address the legacy of issues of our industrial activities when the thinking at the time was that the environment could absorb and dissipate the pollutants, or when corporate and government values did not embrace the ideals of maintaining a clean, pristine environment.
- One looking at today and the future, to ensure that we manage the risks associated with our industries and operations so as to prevent environmental incidents through spills and leaks, and to avoid adverse environmental impacts through discharge of our wastes (emissions to air and water, solids disposal).

Consider these questions:

- Do we have the tools to effectively evaluate the concerns in terms of risk (consequence and probability) in order to provide a prioritized list of topics to work on?
- Do we have the management commitment to follow through in determining just what needs to be done and then to finance it?
- Do we have the answers in place to solve the problems associated with environmental risk?

For the most part we do have the skills and tools to do what is needed and if we do not have them mankind has shown a strong capability of developing what is needed. The trouble is the issues around environmental risk extend well beyond the company fence-line and the forums needed to address the many high priority issues are yet to be placed. For any company executive, this is troublesome simply because you have only so many resources to apply to the issues and you need to know which ones have the higher priority.

Most companies will pay keen attention to the local regulations and ensure they exceed them significantly. The impact of an environmental incident on a company can be huge. CN Rail was significantly impacted by the incident at Lake Wabamun, and the same for Montreal-Maine-Atlantic Rail at Lac-Megantic. As tragic as these incidents were, these are very localized in comparison to others that have happened globally over the years, and in some cases are on-going. Costs for clean-up mount quickly. Effective clean-up processes are not yet developed (look at the EXXON Valdez incident, BP Deepwater Horizon at Macondo, and Lac-Megantic) and are costly. Legal liability and litigation are immense with lawsuits ranging from impacted businesses or local community recreation to real estate values and damages for loss of use. Public outrage will cost a company business meaning lower revenues and hence less profitability. How many people do not purchase gasoline from EXXON because of Valdez? Gasoline from BP because of Deepwater Horizon? The liabilities of an incident, the costs, can severely impact the financial bottom-line of a company. Union Carbide Corporation was extremely successful with its broad line of consumer products. In the aftermath of Bhopal, UCC no longer exists.

So what is the right thing to do? Be part of the solution! Of course, companies and organizations of all kinds should do so as well. Finding the priorities and developing the resources needed to make a difference. Having enlightened management set in place policy and procedures to proactively set the standard not simply meet the standard is where it is at.

We, collectively as a community, a company or organization, a nation, and a global village need to identify the issues, the solutions, the priorities, and the resources to make progress. Before we set on a course to tackle all of the world's problems, we need enlightened management – leaders – to protect our environment from the impact of potential adverse incidents by:

- Setting sound policies and procedures,
- Moving forward faster than legislation, and
- Setting a higher standard.

Concerning bio-fuels: The topic is still evolving. Is bio-fuel really energy-efficient? To make decisions of such enormity is something we as a public need to come around to. The science is lagging as industrial development is expanding. The time is short and the decision models we need are not there or at least not well tested yet.

Concerning Genetically-Modified Organisms and Foods: Again, the topic is evolving! These scientific advances enable global food producers to feeds hundreds of millions of people, if not billions! Is the opposition against the science, or against big agri-business? Are these harming other species? An evolving theory is that GMOF are harming the honey bee populations.

The Current State of Taking on Environmental Challenges:
All people are potentially at risk of global environmental problems. Everyone has a stake. The global leaders, their environmental agencies, governmental and non-governmental multinational organizations, and even for-profit enterprise corporations, are actively working to identify the major concerns, the ones with the gravest concerns, and prioritize the issues. This is where we are today. Although some of the issues are being tackled, many remain.

The State of Our Environmental Challenges:

Currently, the world is trying to decide these issues, based on data.	➢ Identify Hazards and Concerns ➢ Determine all possible consequences ➢ Evaluate probabilities carefully
Where we as a public want to be now. *(We want something done!)*	➢ Prioritize using some sort of criteria ➢ Make decisions to take action ➢ Execute & follow-up actions
Eventually where we should be.	➢ Research and document ➢ Anticipate environmental impacts and address proactively ➢ Make positive changes ➢ Move onwards with strategy that reflects risk management and environmental responsibility.

Conclusions and Key Lessons:

Judge the evidence: Judging evidence in environmental science is very difficult because of the growing complexity and magnitude of information, and the diverse opinions among experts. Be cautious of hidden agenda: Is the opposition to GMF based on science (science has proven the risk is no different, in fact, lower than foods hybridized by conventional methods) or based on opposition to "big agri-business" or based on irrational fear? Be an advocate for being informed, and making informed decisions based on data and evidence.

Challenge misconceptions: Misconceptions about science and the environment dominate public discourse and endanger our ability to recognize the greatest threats to ecological stability. The public has difficulty grasping most concepts (measures, thresholds in "ppb"; green technologies). Provide clarity and "plain language" in the explanations of scientific and engineering concepts. Do your "mass and energy balances" when comparing technologies to reveal the real impacts.

Be responsible: Responsible actions to protect our environment and provide a future for our children must place human needs in a balanced perspective within our environment. Make decisions, such as risk assessments, based on validated evidence.

In short, be part of the solution!

CBC News Article: "Electric cars could boost CO2 emissions":

"Trying to go green by replacing your gas guzzler with an electric car? In some provinces, that may actually be worse for the environment, a University of Toronto researcher says."
http://www.cbc.ca/news/technology/electric-cars-could-boost-co2-emissions-in-some-provinces-1.3007409; Accessed 20150324

CBC News Article: "Pipelines vs Trains: Which is better for moving oil?":

"With 4 oil-train derailments in North America in the past 3 weeks, pipeline-vs.rail debate resurfaces."
http://www.cbc.ca/beta/news/business/pipelines-vs-trains-which-is-better-for-moving-oil-1.2988407 ; Accessed 20160817

Thorough Consideration of Alternatives is Essential:

Which of these broad alternatives is better? A complete, thorough, and all-inclusive environmental impact assessment must be done before embarking on a particular choice. Such an approach is a ripe field for study and research, as unintended consequences may arise with a sub-optimum selection of one alternative over another.

- Pipelines or Rail-cars for transportation of hydrocarbon fuels (natural gas, crude oils, upgraded crude oils / bitumen with light-end diluents, NGLs, gasoline, jet fuel, etc.)
- Electrically-powered vehicles or vehicles powered by internal combustion engines?
- Electrical generating stations powered by wind vs hydro vs coal / non-renewable / fossil fuel vs nuclear?
- Use crops to produce fuel for transportation needs (corn converted to alcohol, soy oil or canola oil converted to diesel) as substitutes for non-renewable / fossil fuel hydrocarbons?
- Expand the crop-growing regions (deforestation) or increase mining for artificial fertilizers to boost production from existing crop-growing regions?
- The impact of de-naturalizing the world and ever-spreading urbanization, or intensifying existing urbanization and industrialization?