Barrier-Focused Approaches to Risk Analysis -Introduction to Bow Tie Analysis

WorkSafeBC Risk Analysis Unit

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Agenda for the session

Learn the process for creating a bow tie

Introduction to Barrier-focused model of accident causation/prevention - *James Reason Swiss Cheese model*

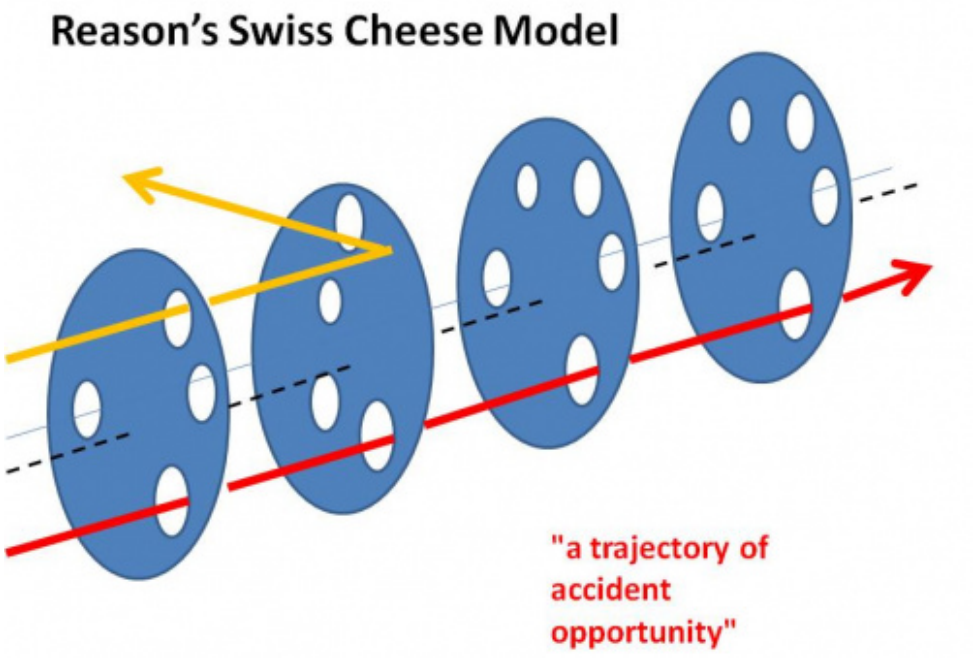
Introduction to Bow Tie Analysis for Hazard/Risk Analysis

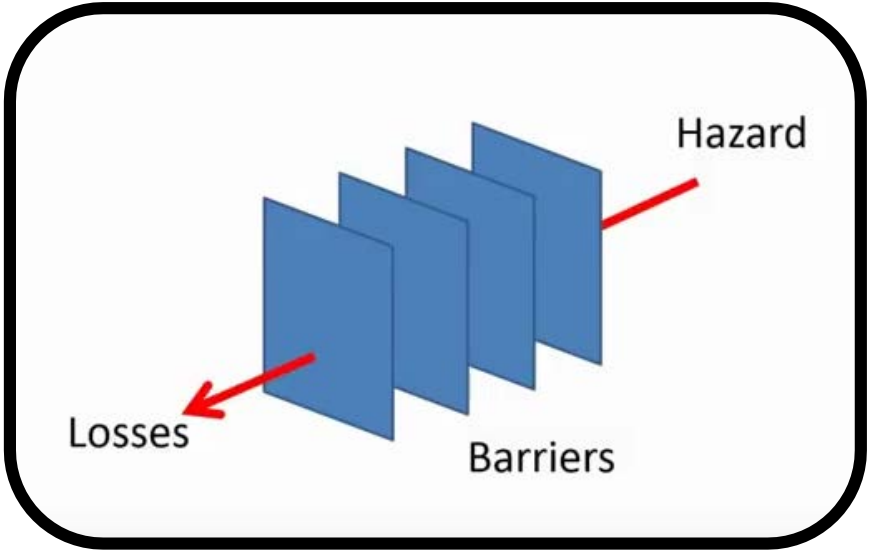
Group Exercise – Construct two Bow Tie diagrams

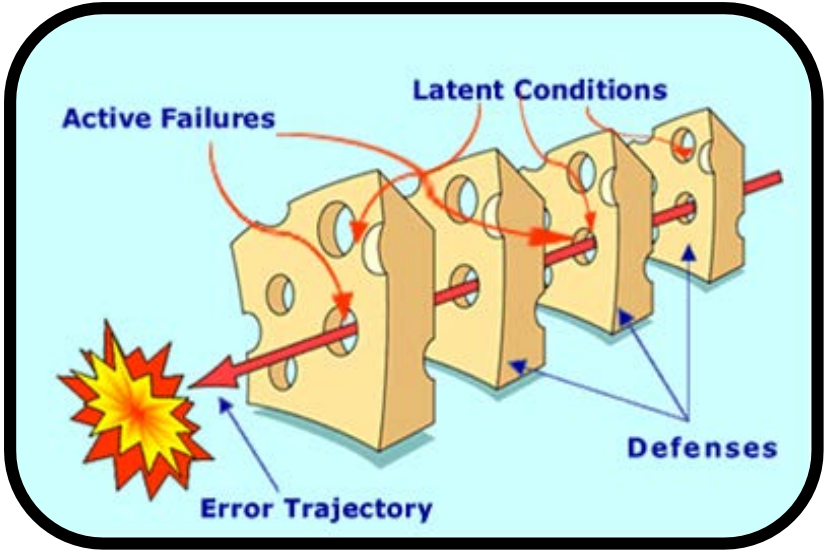
1. Introduction to Barrier-focused model of accident causation/prevention

James Reason Swiss Cheese model

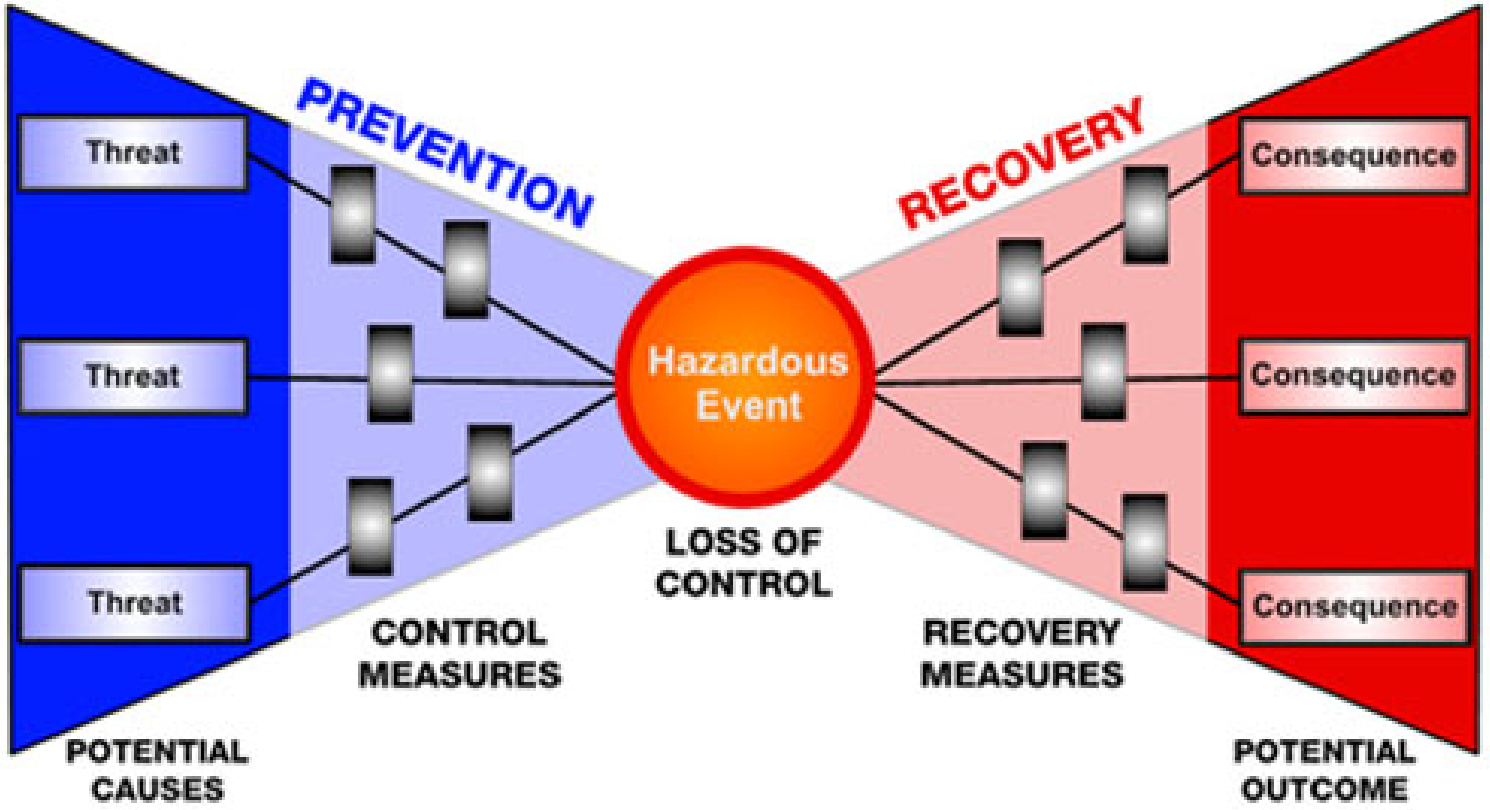
Barrier thinking







Barrier-based approach


PREVENTION
RECOVERY
Threat
Threat
Threat
Hazardous Event
Consequence
Consequence
Consequence
LOSS OF CONTROL
CONTROL MEASURES
RECOVERY MEASURES
POTENTIAL CAUSES
POTENTIAL OUTCOME

What are barriers?

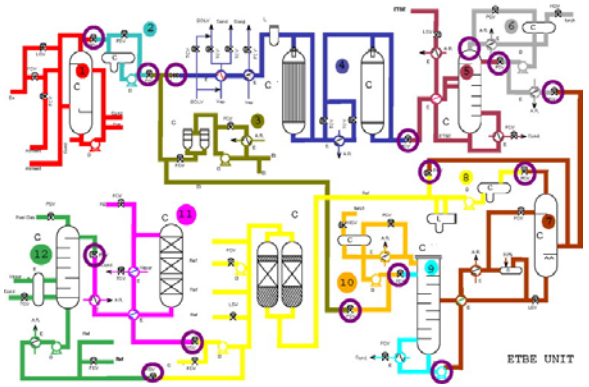
- A barrier (sometimes also called a control) can be any measure that acts against some undesirable force or intention, in order to maintain a desired state.
- Barriers can be hardware systems, design features, work practices etc.
- All barriers are **not** created equal. Some are better and/or more reliable than others.

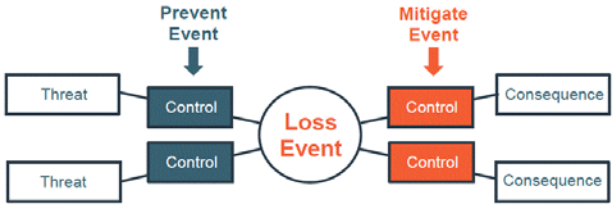
Bowtie XP Methodology manual

2. Introduction to Bow Tie Analysis as a Hazard/Risk Analysis Tool

Assessment / Analysis Tools You May See…..

- HAZID
- HAZOP
- What-If
- Checklist
- JHA – Job Hazard Analysis
- FMEA - *Failure Mode and Effects Analysis*
- LOPA – *Layer of Protection Analysis*
- **Bow Tie Analysis**





What is the objective of these analyses?

- Safe **Design** of Workplace
  - Eliminate hazards
  - Minimize likelihood / severity of potential incidents
- Effective **Controls** (Barriers)
  - Engineering Controls
    - Passive – burst discs, containment berms, fixed guard, etc
    - Active – sensors, automated valves, light curtains etc
  - Administrative Controls
    - Policies, safe work practices (some written), training
    - Signage
  - Personal Protective Equipment

Controls – important considerations

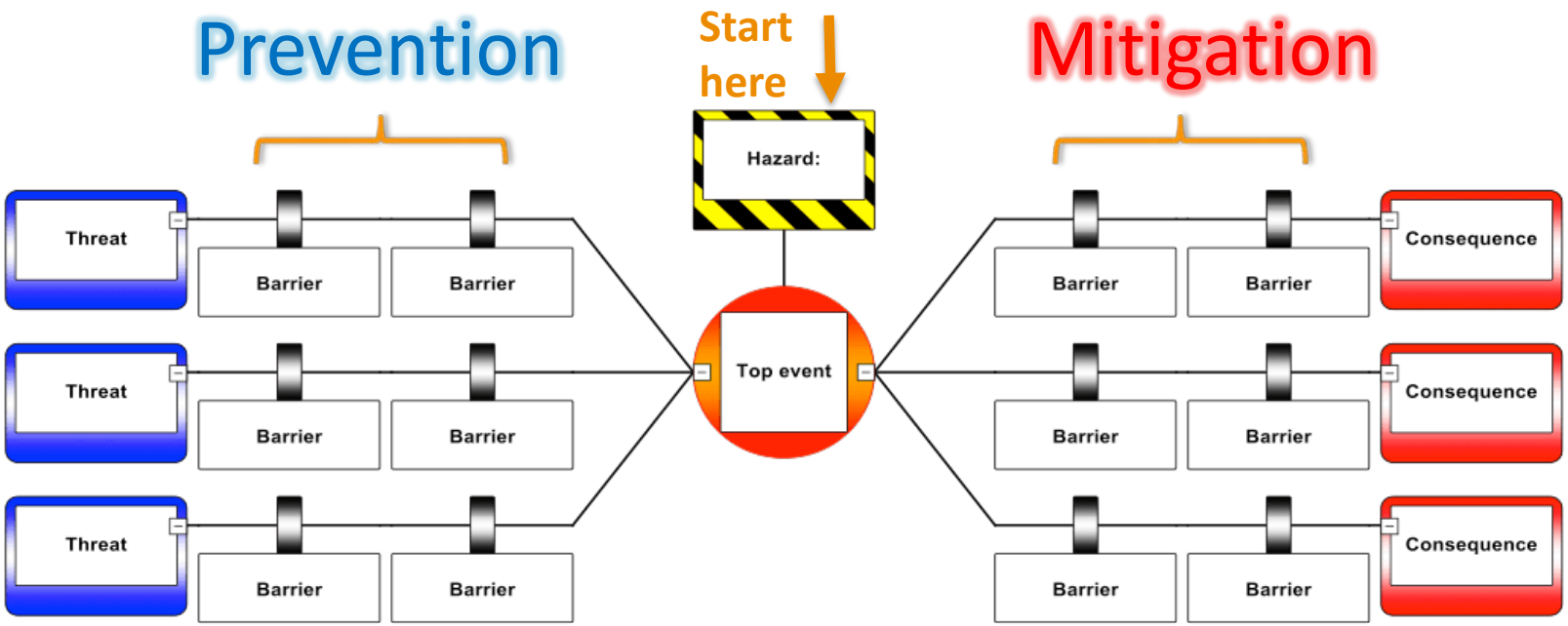
- All controls have administrative elements
  - Gas sensors need calibration and maintenance
  - Warning alarms require human response
  - Workers need to wear correct PPE at right time
- Often controls are part of a control system
  - Detect, decide and act
  - e.g. gas sensor ⇔ computer ⇔ warning lights & sirens ⇔ worker action
- Controls are never perfect. They can:
  - be inadequate, fail, be absent

Who should be involved?

The more diverse it is, the better it is…

- Maintenance
- Operators
- Technical personnel
- Suppliers
- OH&S
- Process engineers

What is the Bow Tie model?



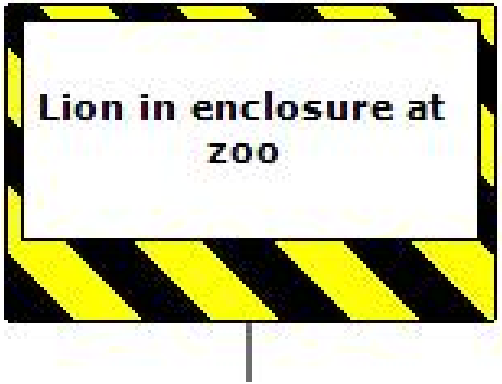
Hazard and Top Event

Hazard

Hazard: A thing, activity, or condition that has the potential to cause harm

Define the context and scope:

- The specific hazardous thing or activity
- The specific hazardous item
- The specific location of hazard



Hazards types

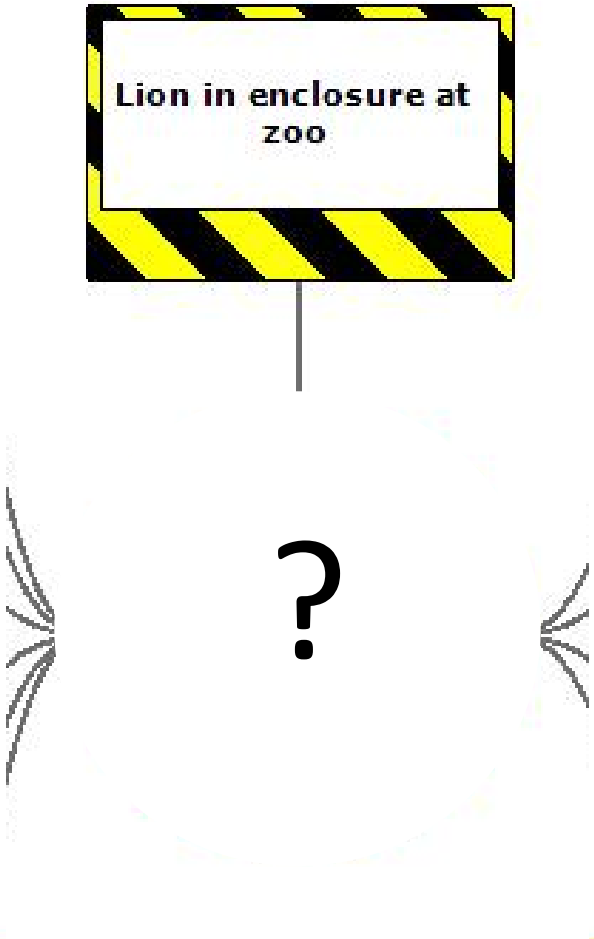
Description	Activity	Condition	Thing
Gasoline stored in a tank			√
Driving chemical tanker truck in urban area	√		
Load suspended by crane		√	
Biogas in the digester			√
Chlorine gas in a pressurized cylinder			√
Aging building structure		√	
Transferring propane	√		

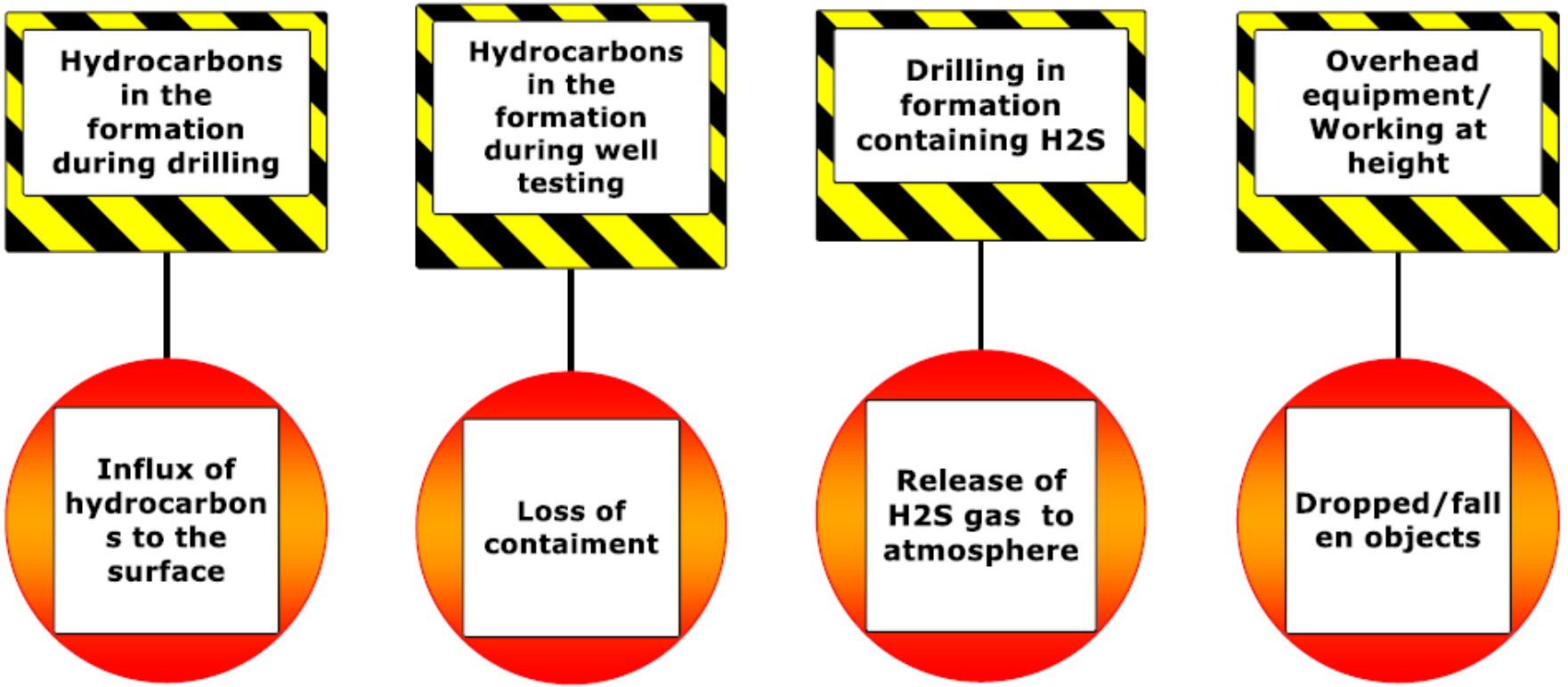
What's the hazard?

Top Event

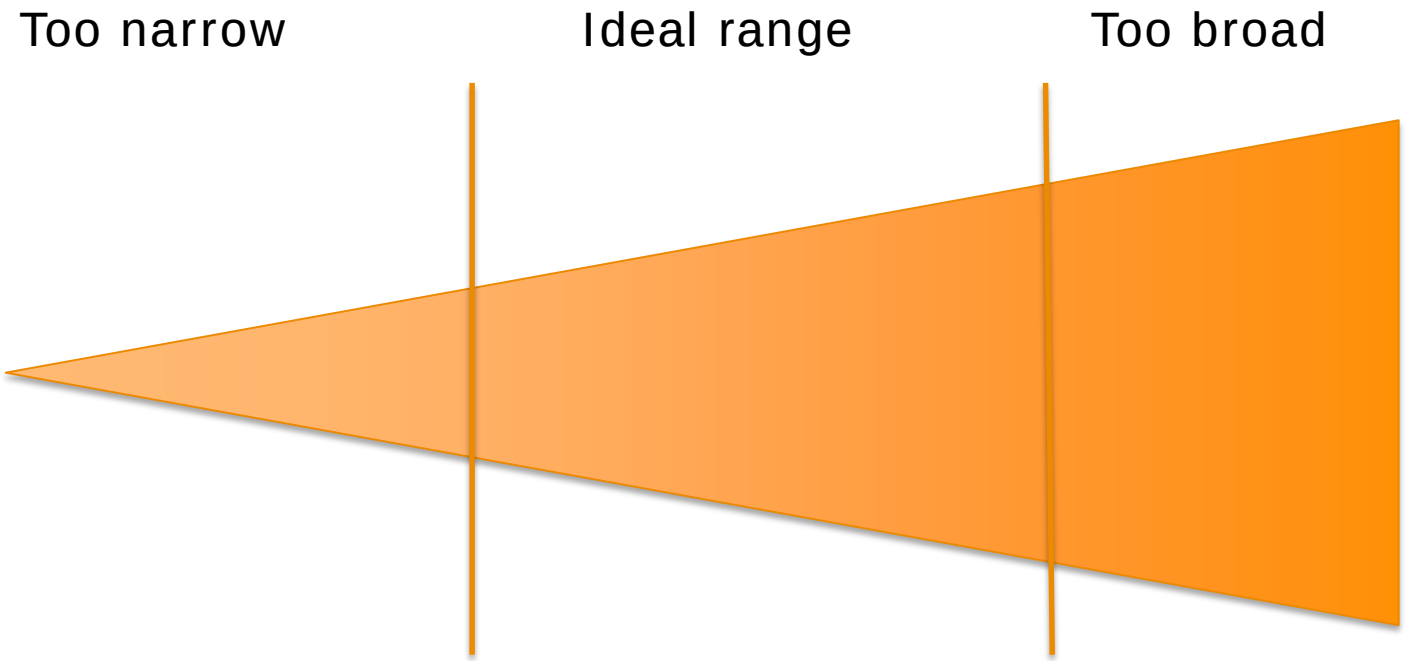
Top event: (Major Unwanted Event)

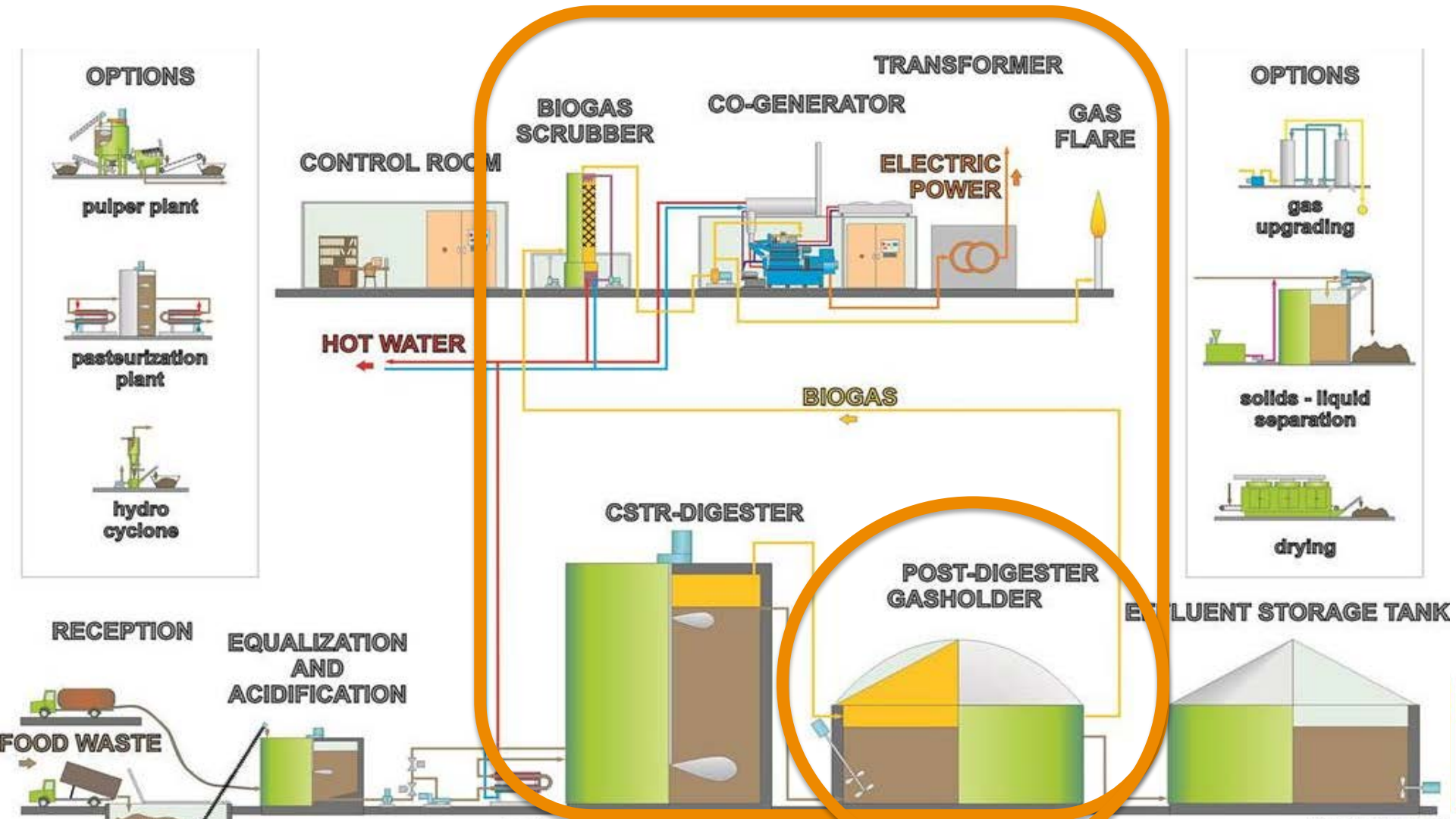
1. Loss of control
2. Loss of containment
3. (or both)

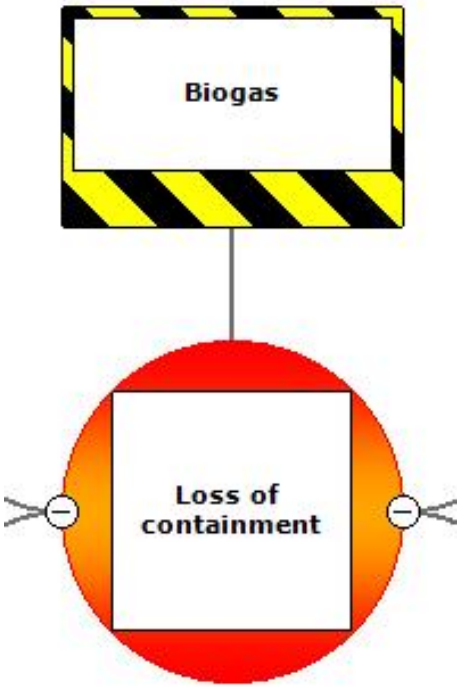


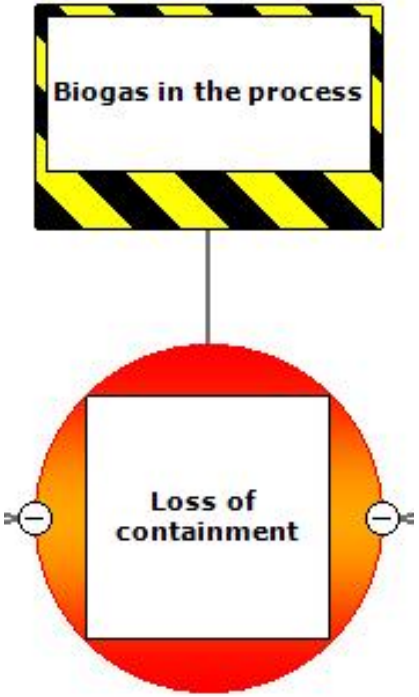

Hydrocarbons in the formation during drilling
Influx of hydrocarbons to the surface
Hydrocarbons in the formation during well testing
Loss of containment
Drilling in formation containing H2S
Release of H2S gas to atmosphere
Overhead equipment/ Working at height
Dropped/fallen objects

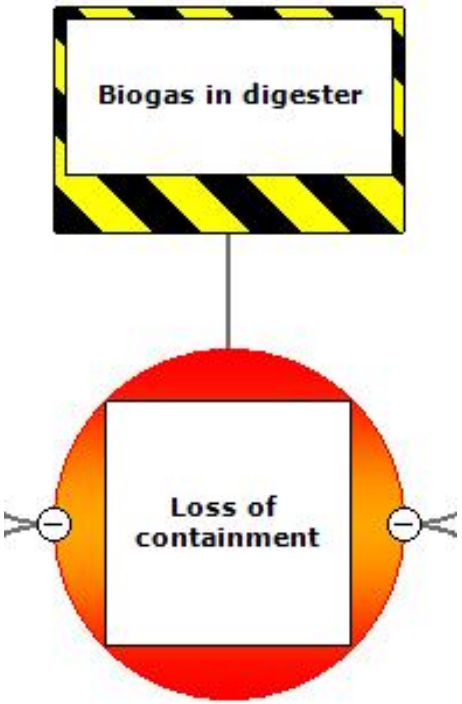
Scope




OPTIONS
pulper plant
pasteurization plant
hydro cyclone
TRANSFORMER
BIOGAS SCRUBBER
CO-GENERATOR
GAS FLARE
CONTROL ROOM
ELECTRIC POWER
HOT WATER
BIOGAS
CSTR-DIGESTER
POST-DIGESTER GASHOLDER
OPTIONS
gas upgrading
solids - liquid separation
drying
RECEPTION
EQUALIZATION AND ACIDIFICATION
FOOD WASTE
LUENT STORAGE TANK


Biogas
Loss of containment


Biogas in the process
Loss of containment


Biogas in digester
Loss of containment

Top Event guidelines

Threats

Threats

Threats: Factor that can cause the top event (i.e. the triggering action or condition).

Threats - Guidelines

- All should be stand-alone
- Should independently lead to the top event
- Should not be a failure of a control
- Try to capture all credible threats in analysis
- Be specific:

'Human Error' – *rather, what is the specific action or non-action?*

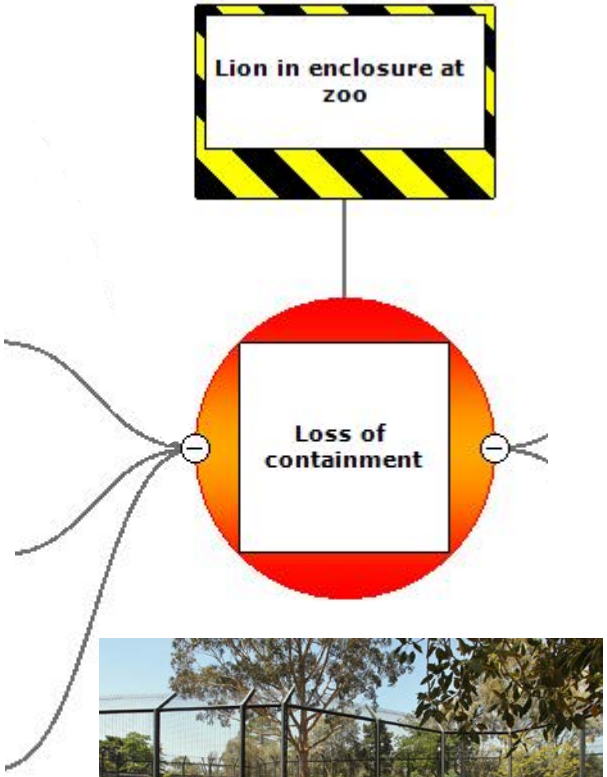
'Poor weather' – *rather, high wind speeds, sub zero temps etc.*

- Note:

➢ If too generic then controls are vague

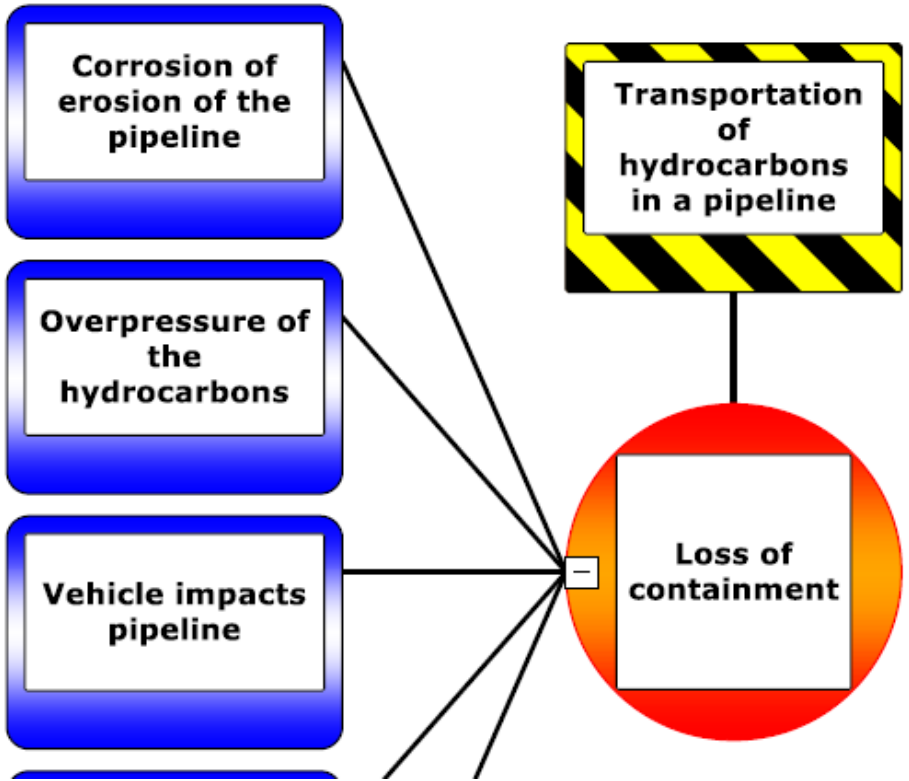
➢ Threats that are too similar will have the same controls

Threats - Lion

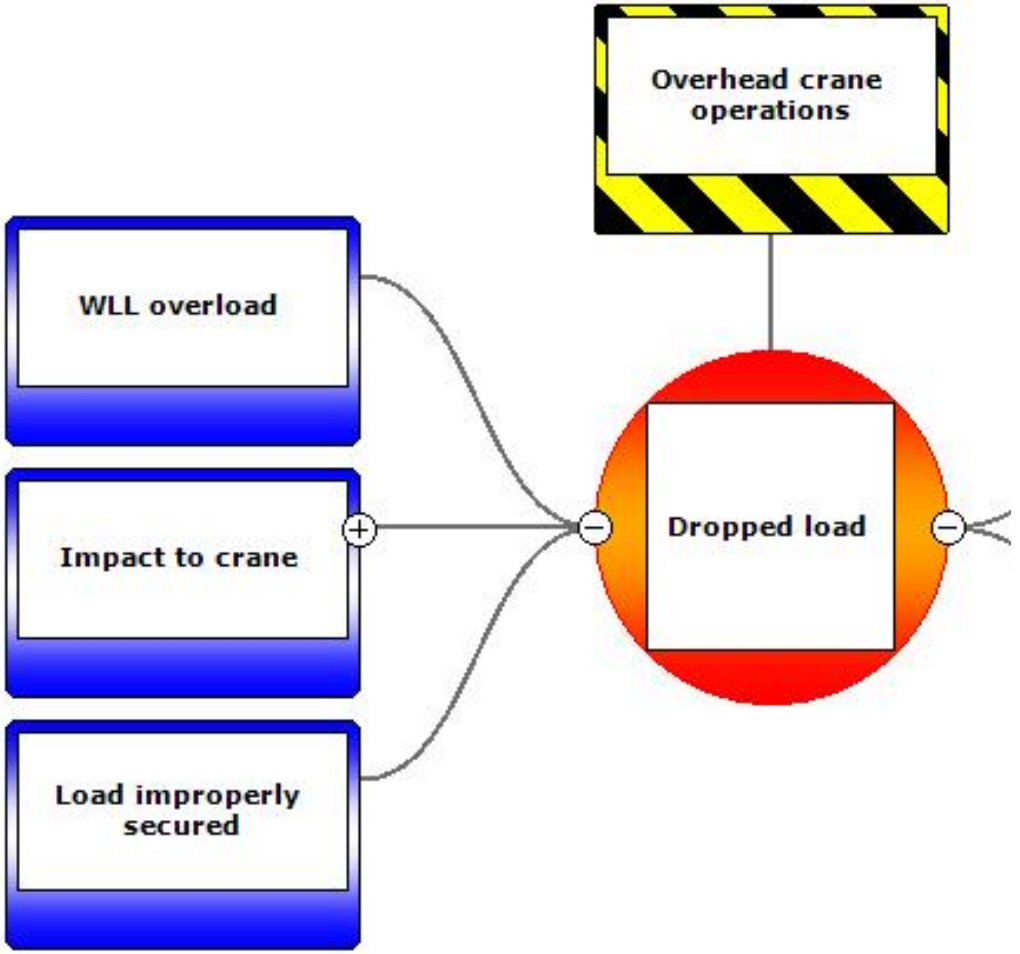


Threats – Oil & Gas

- Over-pressure
- Under-pressure
- Corrosion
- Erosion
- Impact damage
- Vibration



Threats – Crane

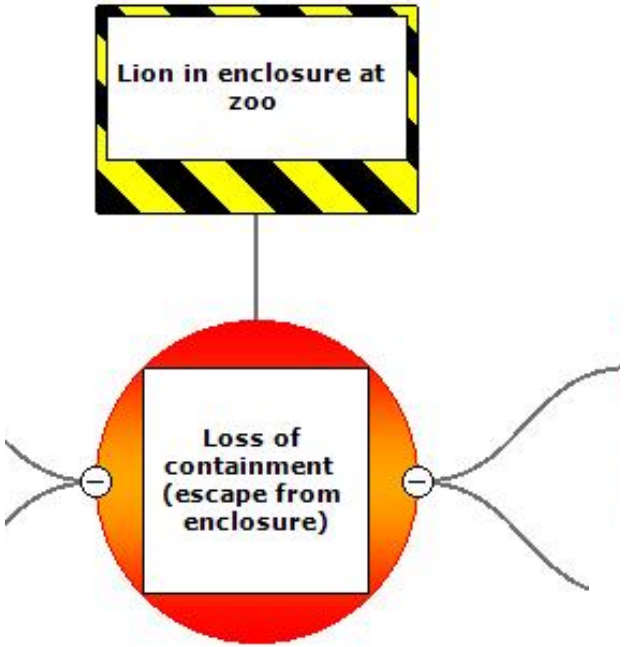


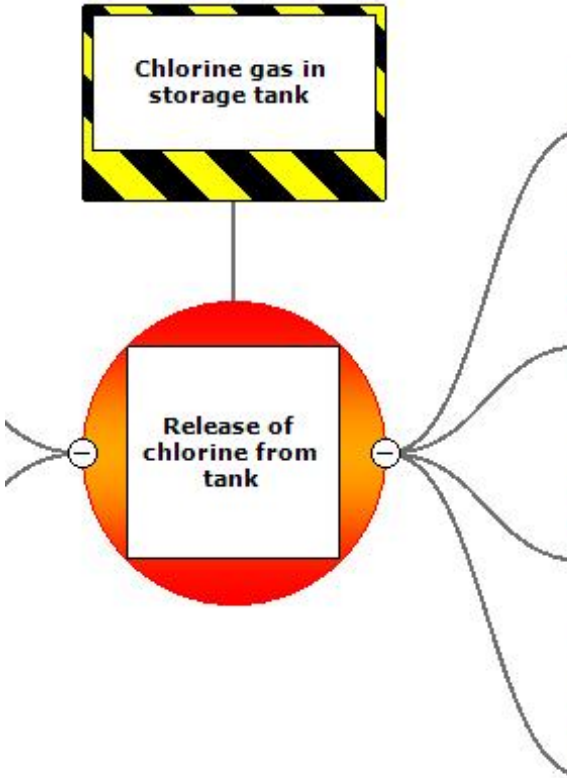
Consequences

Consequences

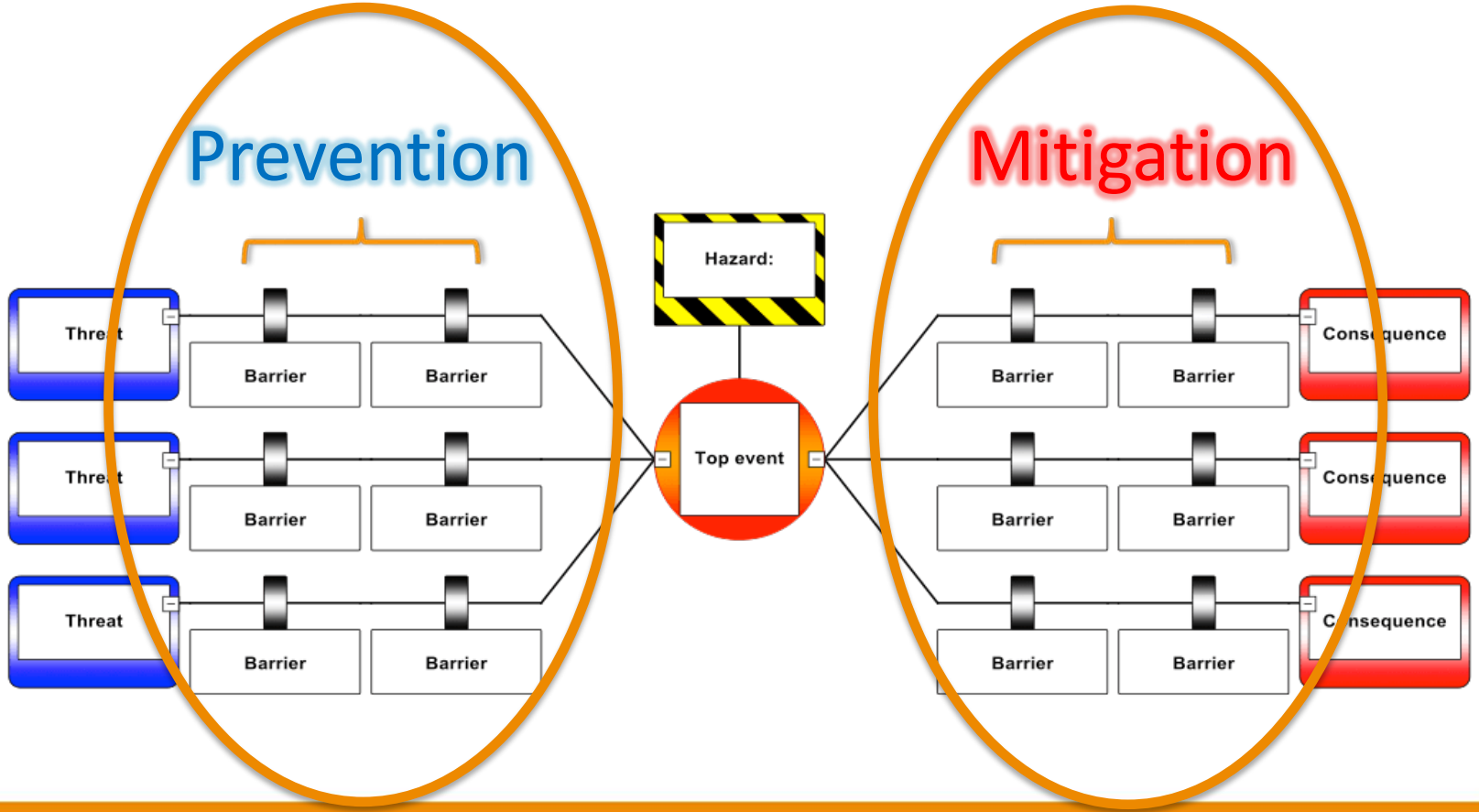
Can be various harmful outcomes to:

- Person/s
- Equipment/Facility
- Organization




Chlorine gas in storage tank
Release of chlorine from tank

Risk Controls
Barriers / Controls


Prevention
Mitigation
Hazard:
Top event
Threat
Threat
Threat
Barrier
Barrier
Barrier
Barrier
Barrier
Barrier
Barrier
Barrier
Barrier
Barrier
Barrier
Barrier
Consequence
Consequence
Consequence

Barriers / Controls

Prevention barriers (Left)

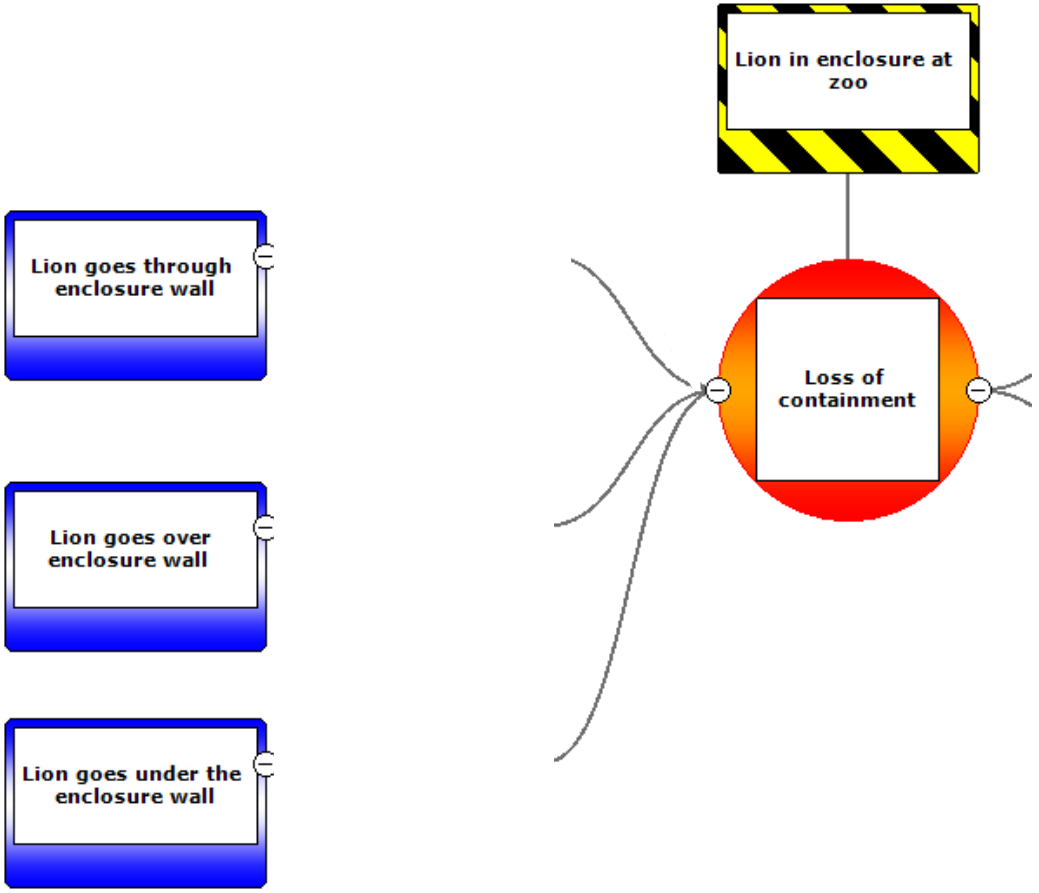
- To prevent the onset of the top event
- Sometimes lessen the effect of the top event
- Include: ‘detect, decide and act’

Mitigation barriers (right)

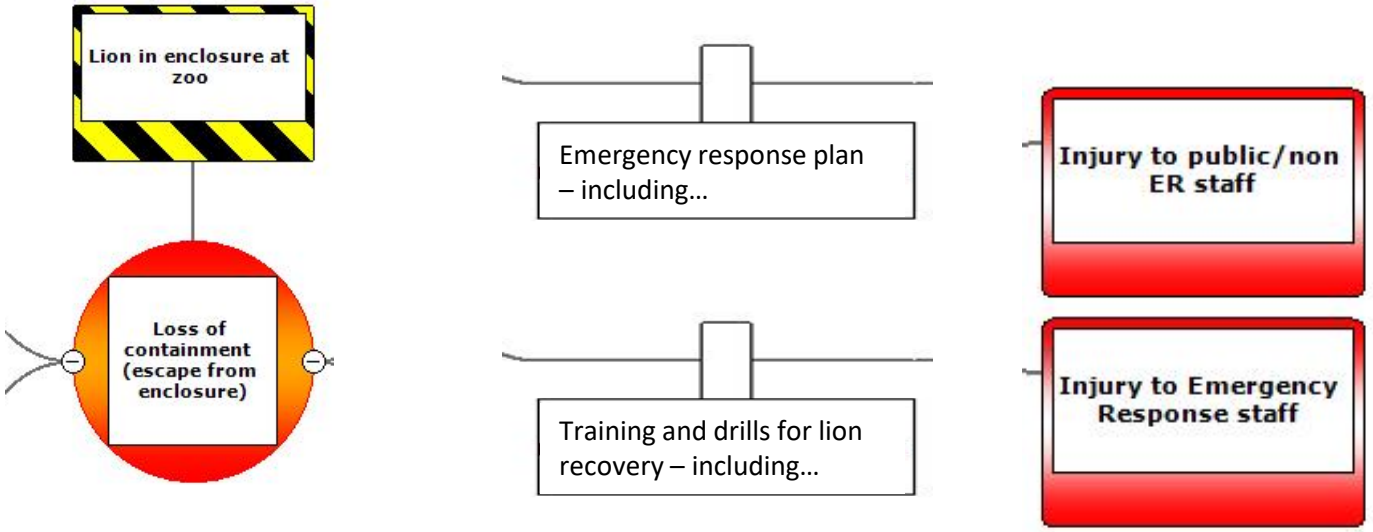
- Reduce / mitigate the severity of the consequence (after top event has happened)
- Sometimes stop the consequence /outcome from happening

EFFECTIVE, INDEPENDENT AND AUDITABLE

Prevention Barriers -Lion Example



Mitigation Barriers – Lion Example



Prevention or Mitigation?

Top Event/Threat/Consequence	Barrier / control	Characterization?
Loss of containment – gasket leak	Appropriate gasket fitted to specifications	PREV
Tank overflow – hydrocarbons affect environment	Dike/Berm	MIT
Loss of control of car – driver impacts dashboard	Air bag	MIT
Loss of containment – major environmental pollution	Detect leak and deploy spill response equipment	MIT
Tank overflow – faulty level gauge	Secondary High-High level indicator	PREV
Dropped object - overloaded	WWL sensor on crane	PREV
Tank rupture - overpressurization	Pressure relief valve	PREV

Hierarchy of Controls

Barriers / controls

Administrative barriers can include:

- Specific policies, safe work procedures, practices

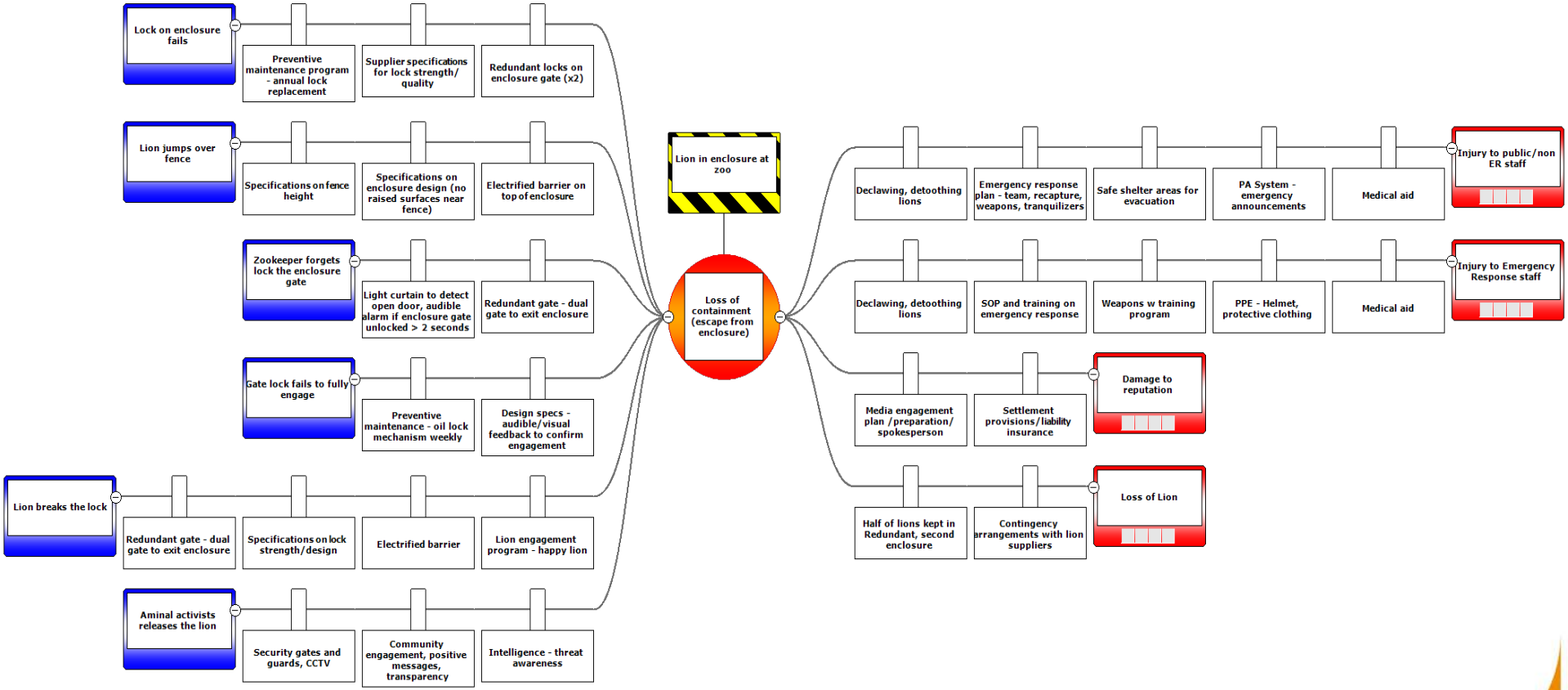
Barriers do not generally include:

- Generic instruction
- Generic training
- Generic competency
- Generic inspections

*However, specific instruction, training, and inspections are an integral part of barrier **verification and maintenance**

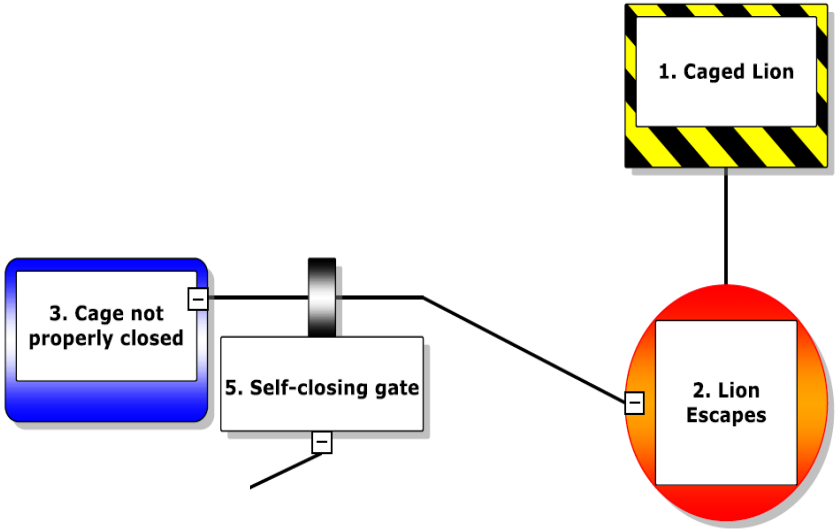
Barriers selection – other considerations

- Are barriers appropriate?
  - Good engineering practice
  - Meet applicable legislation, standards
- Are barriers specific enough to be verified, monitored?
- Are they vulnerable to a common failure mode?
  - i.e. power loss defeats all controls for a threat?
- Do they cover a range of engineering and administrative controls?
  - Include both passive and active controls?
- Do they include both prevention and mitigation controls?


Lock on enclosure fails
Preventive maintenance program - annual lock replacement
Supplier specifications for lock strength/ quality
Redundant locks on enclosure gate (x2)
Lion jumps over fence
Specifications on fence height
Specifications on enclosure design (no raised surfaces near fence)
Electrified barrier on top of enclosure
Zookeeper forgets lock the enclosure gate
Light curtain to detect open door, audible alarm if enclosure gate unlocked > 2 seconds
Redundant gate - dual gate to exit enclosure
Gate lock fails to fully engage
Preventive maintenance - oil lock mechanism weekly
Design specs - audible/visual feedback to confirm engagement
Lion breaks the lock
Redundant gate - dual gate to exit enclosure
Specifications on lock strength/design
Electrified barrier
Lion engagement program - happy lion
Aminal activists releases the lion
Security gates and guards, CCTV
Community engagement, positive messages, transparency
Intelligence - threat awareness
Lion in enclosure at zoo
Loss of containment (escape from enclosure)
Declawing, detoothing lions
Emergency response plan - team, recapture, weapons, tranquilizers
Safe shelter areas for evacuation
PA System - emergency announcements
Medical aid
Injury to public/non ER staff
Declawing, detoothing lions
SOP and training on emergency response
Weapons w training program
PPE - Helmet, protective clothing
Medical aid
Injury to Emergency Response staff
Media engagement plan /preparation/ spokesperson
Settlement provisions/liability insurance
Damage to reputation
Half of lions kept in Redundant, second enclosure
Contingency arrangements with lion suppliers
Loss of Lion

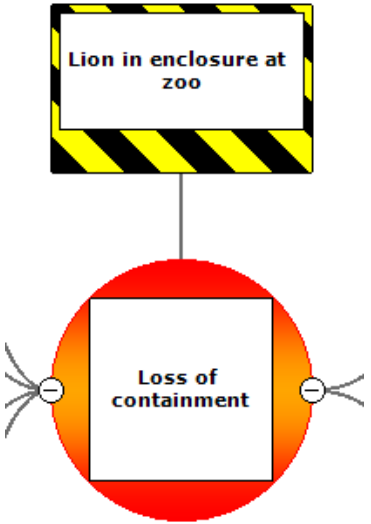
Escalation Factors – In Brief

- Bow Tie Analysis can explore how a barrier could fail
- This may lead to:
  - Measures to minimize potential for barrier failure
  - OR additional barriers may be added (Layers of Protection)
  - OR barrier may be replaced with a more reliable one



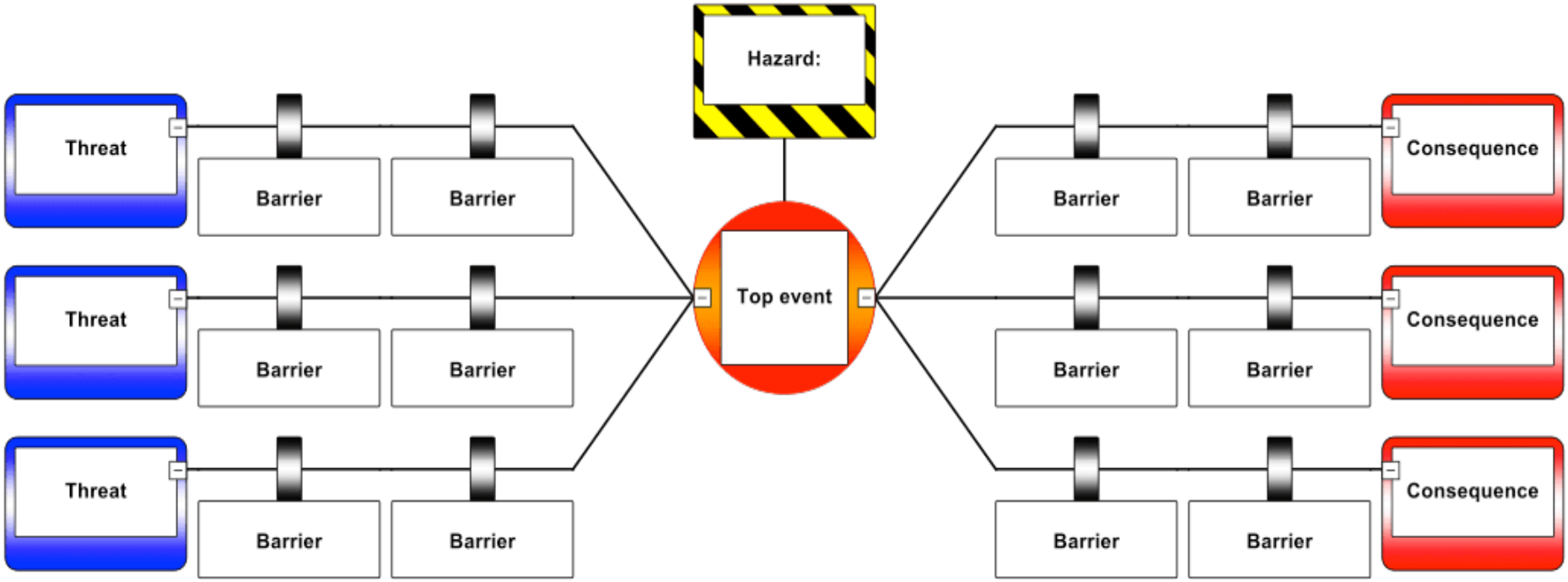
Escalation Factors

- Lion example



Prevention

Mitigation

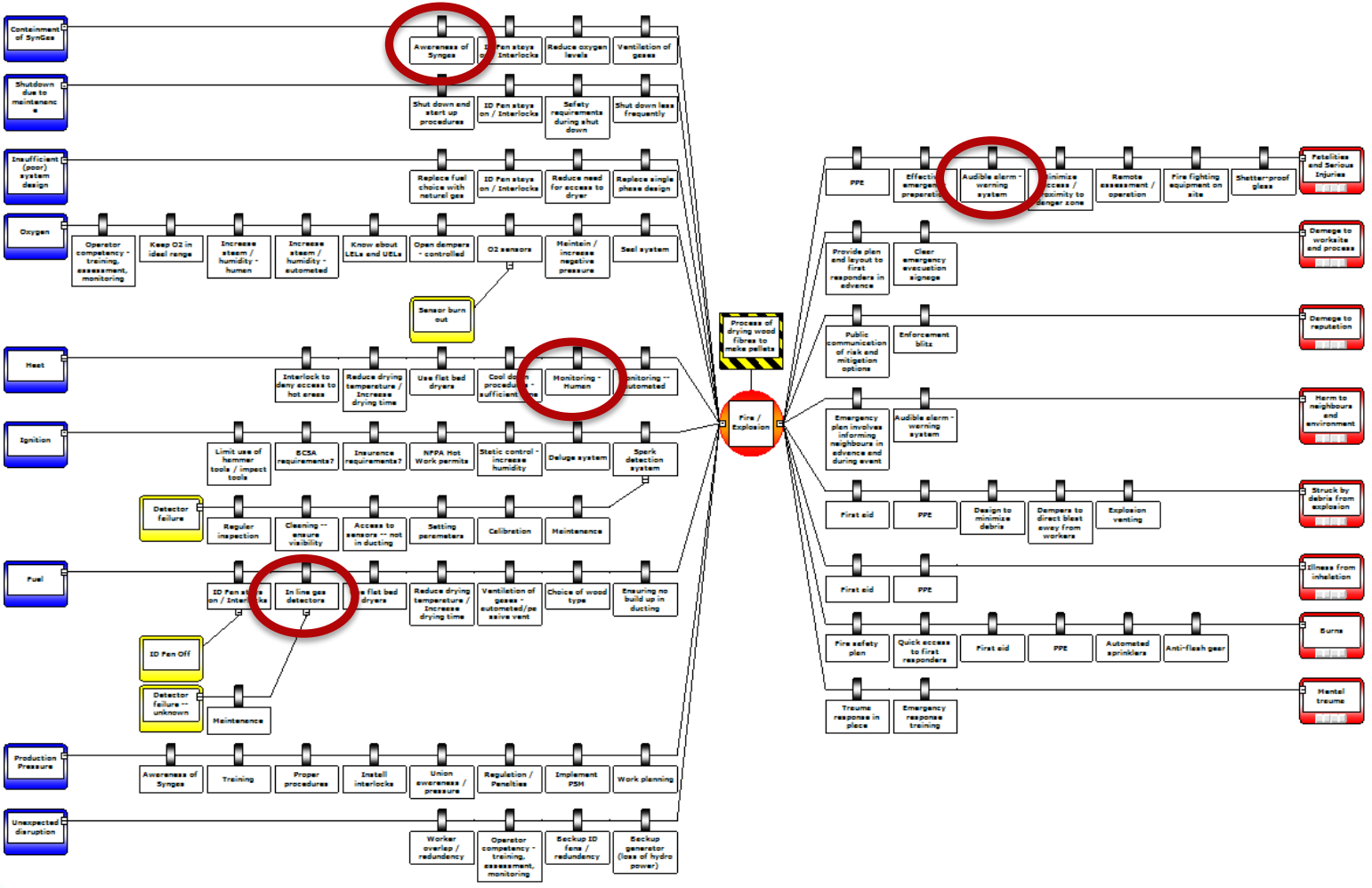


Critical Controls

How Do We Expect Employers to Manage Major Hazards?

What is a critical control?

"A control that is *crucial* to preventing or mitigating a *high* consequence event is critical"

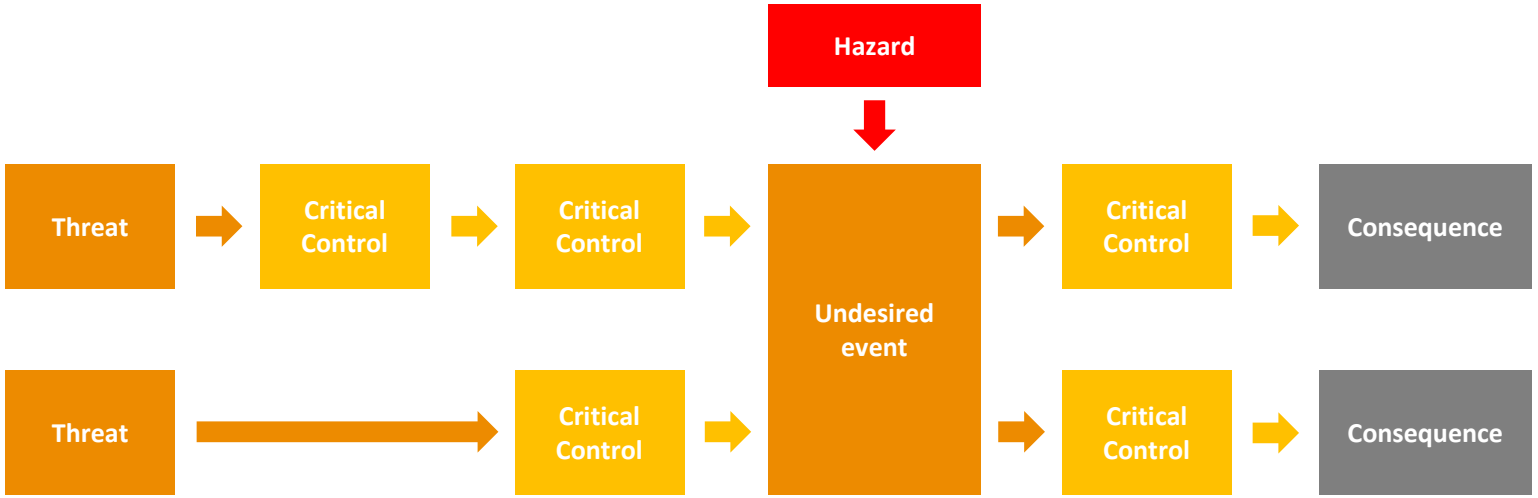

Containment of SynGas
Awareness of Syngas
ID Fan stays on / Interlocks
Reduce oxygen levels
Ventilation of gases
Shutdown due to maintenance
Shut down and start up procedures
ID Fan stays on / Interlocks
Safety requirements during shut down
Shut down less frequently
Insufficient (poor) system design
Replace fuel choice with natural gas
ID Fan stays on / Interlocks
Reduce need for access to dryer
Replace single phase design
Oxygen
Operator competency - training, assessment, monitoring
Keep O2 in ideal range
Increase steam / humidity - human
Increase steam / humidity - automated
Know about LELs and UELs
Open dampers - controlled
O2 sensors
Maintain / increase negative pressure
Seal system
Sensor burn out
Heat
Interlock to deny access to hot areas
Reduce drying temperature / Increase drying time
Use flat bed dryers
Cool down procedures - sufficient time
Monitoring - Human
Monitoring -- automated
Ignition
Limit use of hammer tools / impact tools
SCBA requirements?
Insurance requirements?
NFPA Hot Work permits
Static control - increase humidity
Deluge system
Spark detection system
Detector failure
Regular inspection
Cleaning -- ensure visibility
Access to sensors -- not in ducting
Setting parameters
Calibration
Maintenance
Fuel
ID Fan stays on / Interlocks
In line gas detectors
Use flat bed dryers
Reduce drying temperature / Increase drying time
Ventilation of gases - automated/passive vent
Choice of wood type
Ensuring no build up in ducting
ID Fan Off
Detector failure -- unknown
Maintenance
Production Pressure
Awareness of Syngas
Training
Proper procedures
Install interlocks
Union awareness / pressure
Regulation / Penalties
Implement PSM
Work planning
Unexpected disruption
Worker overlap / redundancy
Operator competency - training, assessment, monitoring
Backup ID fans / redundancy
Backup generator (loss of hydro power)
Process of drying wood fibres to make pellets
Fire / Explosion
PPE
Effective emergency preparation
Audible alarm - warning system
Minimize access / proximity to danger zone
Remote assessment / operation
Fire fighting equipment on site
Shatter-proof glass
Fatalities and Serious Injuries
Provide plan and layout to first responders in advance
Clear emergency evacuation signage
Damage to worksite and process
Public communication of risk and mitigation options
Enforcement blitz
Damage to reputation
Emergency plan involves informing neighbours in advance and during event
Audible alarm - warning system
Harm to neighbours and environment
First aid
PPE
Design to minimize debris
Dampers to direct blast away from workers
Explosion venting
Struck by debris from explosion
First aid
PPE
Illness from inhalation
Fire safety plan
Quick access to first responders
First aid
PPE
Automated sprinklers
Anti-flash gear
Burns
Treume response in place
Emergency response training
Mental treume

Critical control criteria:

1. Is the control crucial to preventing or minimizing the consequences of an event?
2. Is it the only control or is it backed up by another control in the event the first fails?
3. Would it's absence or failure significantly increase the risk despite the existence of other controls?
4. Is the control effective for multiple threats or does it mitigate multiple consequences? Does it repeat in the barrier lines for multiple threats?

ICCM: Good Practice Guide

Preventing the undesired event and **mitigating** the consequences



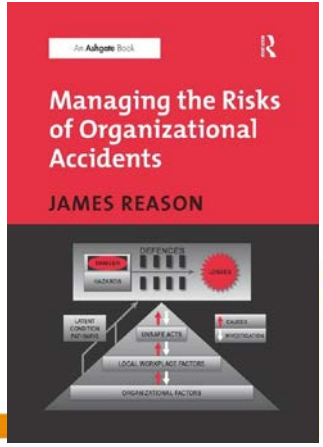
Controls that are crucial to preventing or mitigating the consequences of an event occurring, despite the existence of other controls (ICCM).

Risk Management Resources

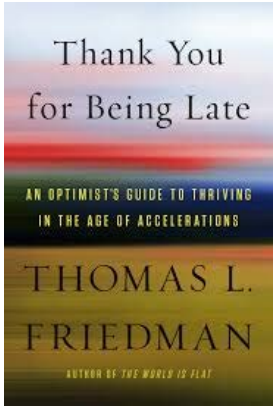
- Established standards and other risk management documents include:
  - OHSAS 18001:2007 (ISO 45001 SMS standard due to be published in Q1 of 2018)
  - CSA Z1000-14 – Safety Management Standard
  - CSA SZ1002-12 – Risk Assessment Standard
  - ISO 31000 – Risk Management Standard
    - ISO 31010 – Risk Management : Risk Assessment Techniques
  - HSG 65 (HSE) – Managing for Health & Safety - Risk Management Section

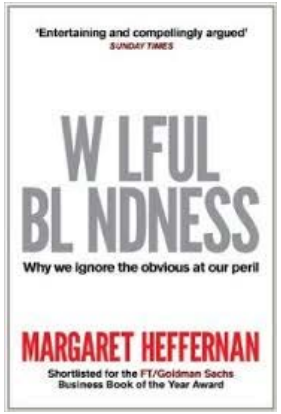
References:

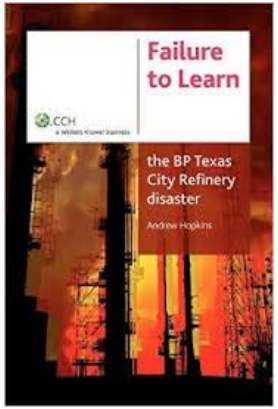
- Bow Ties in Risk Management (2018)A concept book for Process Safety. Center for chemical process safety of the American Institute of Chemical Engineers and Energy Institute . Wiley Publishing, USA.
- BowTie XP Bowtie Methodology Manual. Revision 16 – July 2017
- A Barrier Focused Approach: *How to get started with process safety*, Vol 2. Enform 2016
- Health and Safety Critical Control Management: *Good Practice Guide*. ICMM International Council on Mining and Metals
- Critical control Management: *Implementation Guide*. ICMM International Council on Mining and Metals
- Managing the risks of organizational accidents. James Reason



Further Reading on Risk







Further Reading on Risk