CHENIERE ENERGY, INC.

RISK ASSESSMENT AND RISK MODELS: AN ACTIVITY OR A PROCESS?

INGAA: RISK MODEL WORK GROUP
December 1st, 2016

AGENDA

- Setting the Context: “Begin with the end in Mind”
  - What is the goal?: 4 P’s
  - Drivers: The Industry Landscape
  - How is this managed?: A “Management of Risk” Model
- Process Hazard Analysis:
  - When to start and what PHA methods apply?: Life cycle model
  - Success Factors and Potential Pitfalls
  - Methods: HAZID; HAZOP; LOPA/SIL; FMEA: Inputs/Process/Outputs
- Critical Technical Safety Studies: Inputs/Process/Outputs
  - Human Factors; Dispersion and Consequence Modelling; Fire and Explosion Analysis; Facilities Siting Study; Emergency Systems Survivability Analysis; Quantitative Risk Assessment
- Governance and Assurance
  - Sustainability Model
  - Baseline: Risk Matrix
  - Review and Verify: BowTie Analysis
  - Continuous Improvement: Lessons Learned
- Conclusions and Summary

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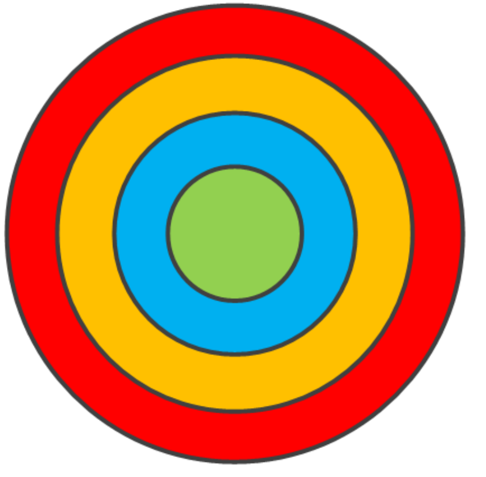
Setting the context: What is the goal?

- Stephen Covey Habit: “Begin with the End in Mind”

- For a Company:
  - Why do we exist? **Profit**
  - What do we require? **Plant**
  - How is that achieved? **Process**
  - Who is going to do it? **People**

  - The 4 P’s Concept



Setting the Context: BASIS FOR COMPLIANCE

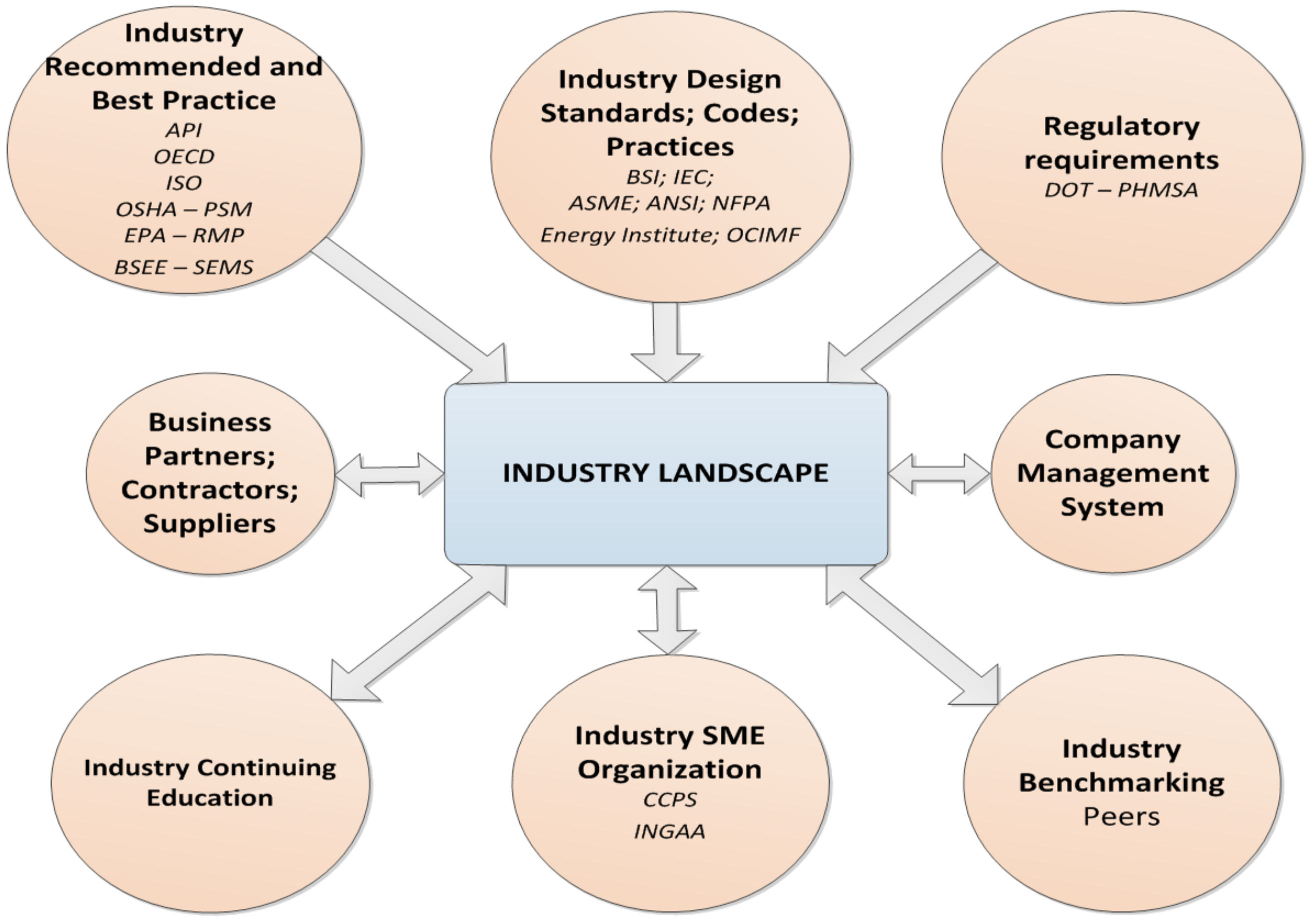
- Check the box?
- Meet regulatory minimum compliance? Relevance? Currency?
- What about best practices – RAGAGEP?
- Is it an organizational Core Value?

- RELEVANT REGULATIONS AND STANDARDS
  - DOT - PHMSA
  - NFPA
  - ASME B31

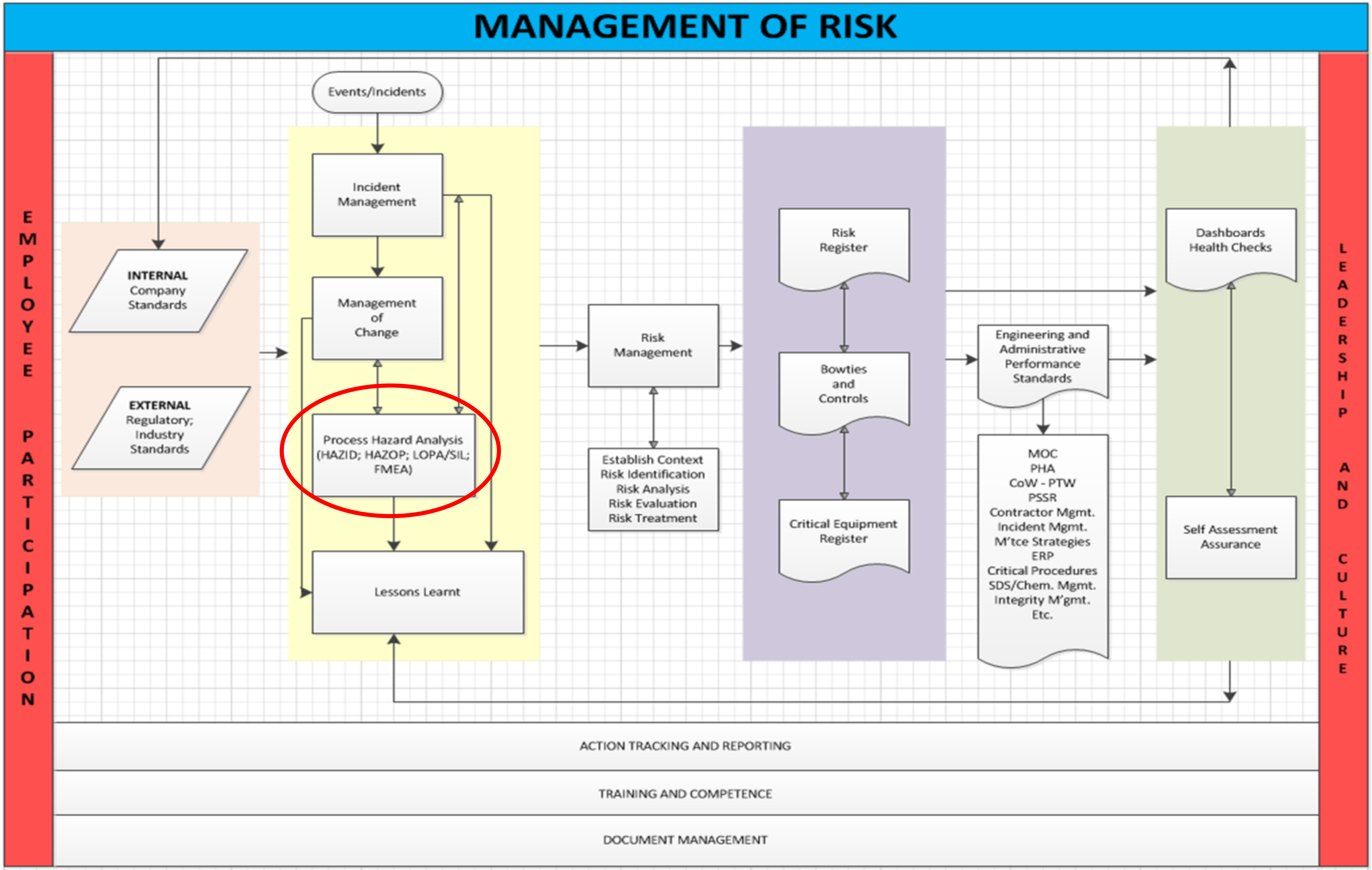
- RAGAGEP
  - OSHA PSM;
  - EPA-RMP;
  - BSEE – SEMS;
  - Safety Case (UKHSE; NOPSEMA);
  - API 1173
  - IEC 61508/61511: SIL

Setting the Context: What are the drivers?

- What are the drivers to enable the goals?



Setting the Context: How is this managed?



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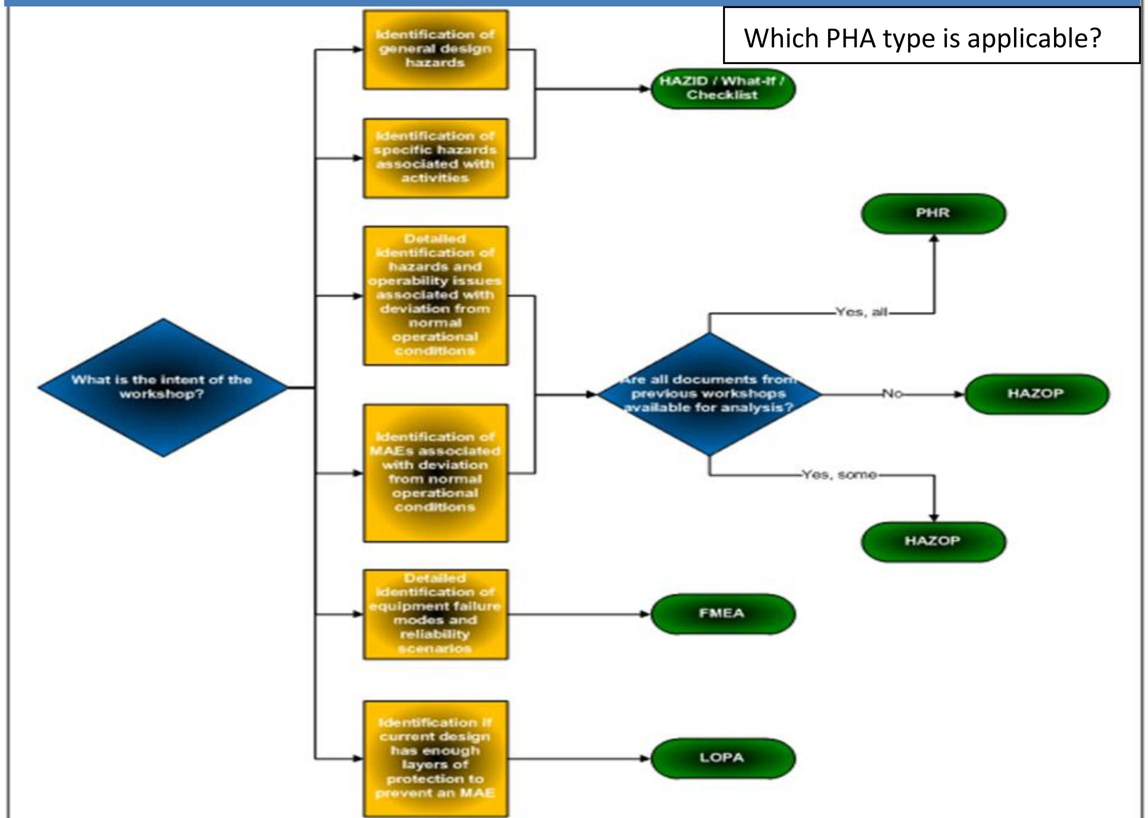
When to start and which Process Hazard Analysis applies?

Table and decision tree to determine when to carry out which PHA Study

	Life Cycle				
	IDENTIFY	SELECT	DEFINITION	EXECUTION	OPERATIONS
Possible Studies	• HAZID • What-If • Checklist	• HAZID • What-If • Checklist	• HAZID • What-If • Checklist • LOPA • FMEA • HAZOP	• HAZID • What-If • Checklist • LOPA • FMEA • HAZOP	• HAZID • What-If • Checklist • LOPA • FMEA • HAZOP • PHR

When to carry out a PHA: Facility Life Cycle?

Which PHA type is applicable?



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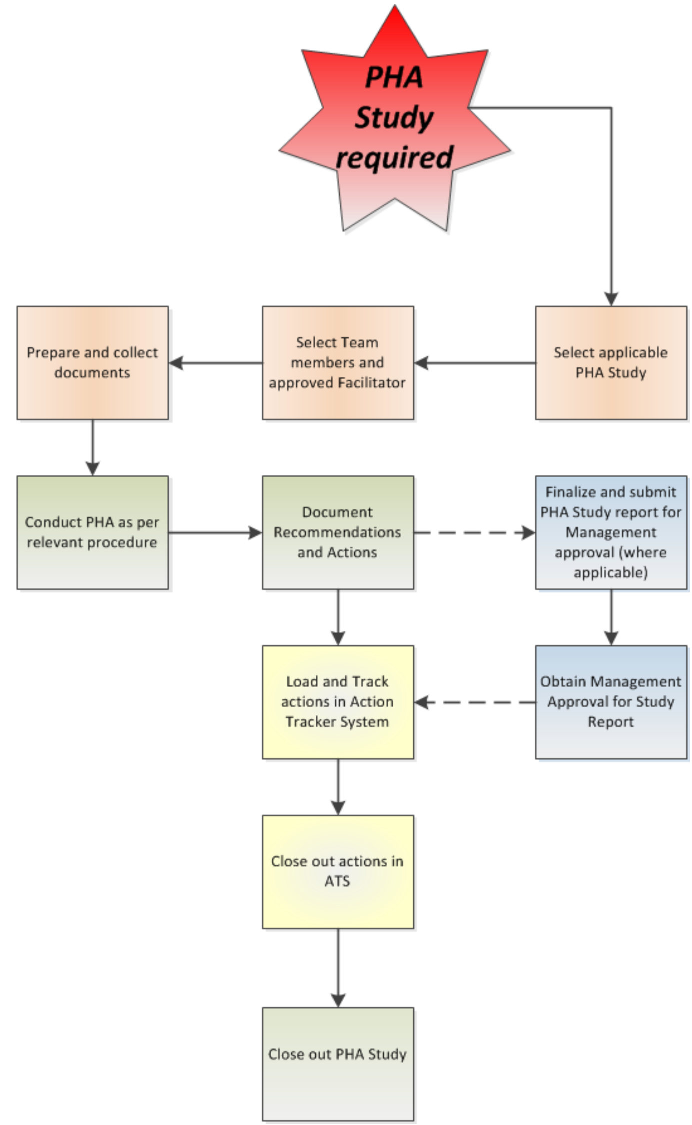
Setting the context: What is the goal?

- PHA selection based on the:
  - Size and complexity of the facility
  - Duration and complexity of the activities or life cycle phase being considered
  - Nature of the activities and processes associated with the facility

- The selected PHA should:
  - Be systematic and structured
  - Foster creative and lateral thinking about possible hazards including those not previously experienced
  - Be appropriate for the facility and the stakeholders
  - Consider which approach will extract the maximum quantity of useful information



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PHA Success Factors

- Active stakeholder engagement and input in the PHA process
- A comprehensive and accurate description of the facility: drawings, process information, existing conditions, modifications, procedures and work instructions, hazardous materials information, etc.
- Systematic and structured, fostering creative thinking inclusive of extracting the maximum quantity of useful information
- Assumptions and uncertainties are explicitly identified and recorded
- Documented records that provides potential major accident events (MAEs) and hazards along with the underlying causes/consequences, control measures and any assumptions
- "SMART" (specific, measurable, attainable, realistic and timely) actions that can be managed and closed out through an auditable trail

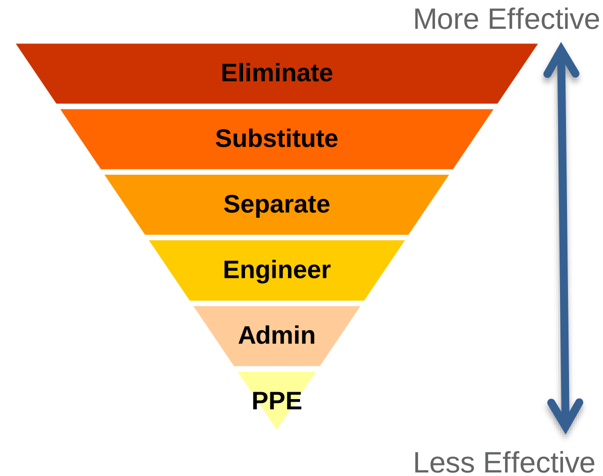
PHA Potential Pitfalls

- Complacency: Just because an incident has not occurred in the past does not mean that it can't happen in the future
- Being too generic: in identification of hazards and potential MAEs. Causes and consequences need to provide plausibility and specificity
- Determination of the underlying cause and not the symptom
- Lack of understanding and assessing impacts from varying process conditions and activities (start-up; shut-down; emergency shut-down; maintenance etc.)
- Inadequate documentation: insufficient recording of underlying assumptions, uncertainties, knowledge gaps, hazard details, incidents, effectiveness of control measures, etc.
- Equal stakeholder participation: seeking full engagement

PHA: HAZID

There are different types of Hazard Identification Methods employed: What-If/Checklist or HAZID

- Inputs:
  - Activities at the specific location
  - Risk Matrix, Tolerability criteria and existing effective controls
  - List of applicable Guidewords
- Process:
  - Brainstorming using SMEs, Guidewords, Risk Assessment
  - Documented in spreadsheet template or software
- Outputs:
  - List of main hazards
  - List of effective safety measures/controls
  - Gaps in existing control measures
  - Recommendations and actions to address gaps



	HAZARD IDENTIFICATION GUIDEWORDS		
Hydrocarbons	**Cold Surfaces**	**Open Flame**	**Pressurized Equipment**
Crude oil under pressure	Process piping -25 to -80C (-13 to - 112F)	Heaters with fire tube	Process piping equipment > 100 psig and < 1000psi
Crude oil at low pressure	Piping/equipment < -80C (-112F)	Direct fired furnaces	Piping equipment >1000 psig
LPGs (propane+ pressurized at normal temp)	**Cold fluids**	Flares	Vacum
LNGs (natural gas pressurized at cryo temp)	Fluids with Temperatures -25 to -80 C (-13 to - 112F)	Cutting torch	**Electromagnetic / Radioactive**
Condensate, NGL (heavy end of natural gas, liquified at normal temp)	Fluids with Temperatures > -80C (-112F)	Pilots (BMS)	Ultraviolet radiation
Natural gas	**Hot Surfaces**	**Electricity**	Infra-red radiation
Wax	Process piping equipment <150 C (302F)	Voltage >50-440V in cables	Microwaves
Refined Hydrocarbons	Piping equipment >150 C (302F)	Voltage >50-440V in equipment	Lasers
Lub & seal oil	Engine & turbine exhaust	Voltage >440V	NORM
Hydraulic oil	Steam piping	Lightning discharge	**Vibration**
Diesel fuel	**Hot fluids**	Electrostatic energy	Metal fatigue causation
Gasoline	Fluids with Temperatures 100-150 C (212- 302F)	Battery operated equip	Environmental noise (community nuisance)
Other flammables	Fluids with Temperatures >150 C (302F)	Classified Areas (ignition of flammables)	**Corrosive Substances**
Flammable Waste (used oil, used filters, etc)	**Temperature Hazards**	**Pressure Hazards**	Hydrofluoric Acid
Drums with chemicals (products)	Temperature Differential Stress	Hydraulic hammer	Hydrochloric acid
Dry vegetation	Piping/equipment above / below thermal limits of material	Water under pressure (> 5 psig)	Sulphuric acid
Welding gas	**Asphyxiates**	Non hydrocarbon gas cylinders	Caustic soda
Paint & coatings	Confined Space	Air under pressure (> 5 psig)	Corrosion
Wood, paper, Class A fires		High pressure differential	
Toxic liquids	**Toxic gases**	**Mechanical Hazards**	**Human Factors**
Mercury	H2S, sour gas	Sharp edges or points	Work stations
Methanol	Exhaust fumes	Rotating equipment	Lighting
Glycol	SO2	Reciprocating equipment	Incompatible hand controls
Brines	Benzene	Pinch points	Awkward location of w/place
De-emulsifier	Chlorine	Stored energy (spring / weights / flywheel)	Mismatch of work to physical
Corrosion inhibitors	Welding fumes	Inadequate design	Long & irregular work hours
Scale inhibitors/antifoulant	CFCs	**Hazards associated with:**	Poor organisation & job design
Degreasers	Nox	Personnel at height	Work planning issues
Isocyanates	Carbon Dioxide (CO2)	Overhead equipment	Indoor Climate
Amines	**Ergonomic Hazards**	Personnel below grade	Language barrier
Oxygen scavenger	Manual materials handling (lifting)	**Objects under induced:**	**Security Related hazards**
Produced water	Loud, steady noise >85 dBA	Objects under tension	Hi-jacking/Piracy
Grey and/or black water	Heat stress	Objects under compression	Assault
Biocides	Cold stress	**Biological Hazards**	Sabotage
Drag Reducer	High humidity	Poisonous Plants	Theft, pilferage
Toxic Solids	Vibration	Large Animals	Civil Arrest
Asbestos	**Dynamic Situation**	Small animals	**Environmental Hazards**
Pig trash	On land transport (driving)	Food borne bacteria	Special Weather Condition (tornados, hurricanes, etc)
Dusts	On water transport (boats)	Water borne bacteria	Sea state/river currents
Heavy Metals	In air transport (flying)	**Medical**	Tectonic activity
Oil based sludges	Boat collision hazard	Medical Treatment on Site	Unstable soil

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PHA: HAZOP

- Inputs:
  - Documentation to support scope: P&IDs; Safe Charts; Operating Limits; PFDs; BOD; incident reports
  - Core team of Subject Matter Experts
  - Definition of the respective boundaries to be assessed (nodes)
  - Risk Matrix, Tolerability criteria and existing effective controls
  - List of applicable Guidewords
- Process:
  - Using SMEs, Parameters and Guidewords, Risk Assessment
  - Documented in spreadsheet template or software
- Outputs:
  - List of deviations from design intent (causes/consequences)
  - List of effective safety measures/controls
  - Gaps in existing control measures
  - Recommendations and actions to address gaps

		GUIDEWORD						
		NO	MORE	LESS	AS WELL AS	PART OF	REVERSE	OTHER THAN
PARAMETER	FLOW*	X	X	X	X	X	X	O
	PRESSURE*		X	X				O
	TEMPERATURE*		X	X				O
	LEVEL		X	X				O
	PHASE		X	X				O
	COMPOSITION	X	X	X				O
	OPERATION	X	X	X	X	X	X	X

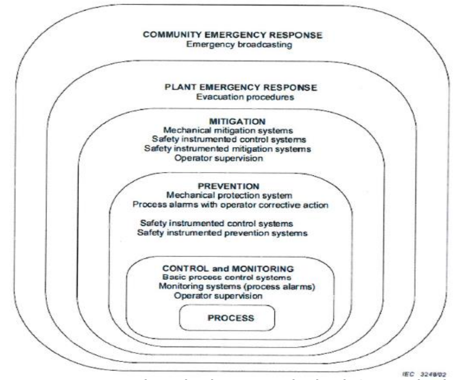
*MAIN PARAMETERS

USUAL X   OPTIONAL O   NOT USED

GUIDEWORD	MEANING
NO	No part of the design or operating intent is achieved
MORE	Quantitative increase - more of the intention occurs or is achieved
LESS	Quantitative decrease - less intention occurs or is achieved
AS WELL AS	Qualitative increase - all the intention is achieved with some addition
PART OF	Qualitative decrease - only some of the intention is achieved
REVERSE	Opposite / reverse of the intention.
OTHER THAN	Something else happens - no part of the intention occurs

PHA: LOPA / SIL

- Inputs:
  - From HAZOP/QRA: hazardous events, frequency, consequence, controls
  - Documents: P&IDs; Cause and Effect Chart; Operating Limits; PFDs; BOD; incident reports
  - Rules/Criteria: frequencies – initiating cause (ICL); maximum acceptable (MAF); probability of failure on demand (PFD); conditional modifiers (CM); Safe Failure Fraction (SFF)
- Process:
  - Identify Independent Protection Layers (IPLs) and type
  - Calculate the LOPA Ratio (LR): MAF
  - For LR<1: identify additional IPL and/or SIS
  - Document in spreadsheet template or software
- Outputs:
  - List of effective layers of protection (safety measures/controls)
  - Safety Instrument System and Safety Integrity Level
  - Gaps; recommendations and actions to address gaps



Source: International Electrotechnical Commission

Initiating Cause	Likelihood (events/year)
Pressure Vessel failure	10^{-6}
Piping failure - 100m - full breach	10^{-5}
Piping leak (10% section) – 100m	10^{-3}
Atmospheric tank failure	10^{-3}
Gasket / packing blowout	10^{-2}
Turbine / diesel engine over speed with casing breach	10^{-4}
Third party intervention (external impact by backhoe, vehicle, etc.)	10^{-2}
Crane load drop	10^{-4} / Lift
Lightning strike	10^{-3}
Safety valve opens spuriously	10^{-2}
Cooling water failure	10^{-1}
Pump seal failure	10^{-1}
Unloading / loading hose failure	10^{-1}
BPCS instrument loop (sensor, controller end element failure)	10^{-1}
Regulator failure	10^{-1}
Small external fire	10^{-2}
Large external fire	10^{-3}
Overall failure of multiple-element process (e.g. "lock-out tag-out procedure)	10^{-3} / opportunity
Operator failure to execute routine procedure (assumed well trained, unstressed, not fatigued)	10^{-2} / opportunity

Table 10.a Typical Frequency Values, ICL, Assigned to Initiating Events (Reference Data from "Layer of Protection Analysis" CCPS, 2001)

IPL	Comments	PFD
Relief Valve	Prevents system exceeding specified overpressure. Effectiveness of this device is sensitive to the service and experience.	10^{-2}
Rupture Disc	Prevents system exceeding specified overpressure. Effectiveness of this device is sensitive to the service and experience.	10^{-2}
Basic Process Control System	Can be credited as an IPL if not associated with the initiating event being considered.	10^{-1}
Safety Instrumented Functions (Interlocks)	See IEC 61508 (IEC, 1998) and IEC 61511 (IEC, 2001) for life cycle requirements and additional discussion	

Safety integrity level (SIL)	Probability of failure on demand average range (PFD avg)	Risk reduction factor (RRF) (RRF = 1/PFD)
0	10^{-1} to 1	1 to 10
1	10^{-2} to 10^{-1}	10 to 100
2	10^{-3} to 10^{-2}	100 to 1,000
3	10^{-4} to 10^{-3}	1,000 to 10,000

Source: "Layer of Protection Analysis" CCPS, 2001

PHA: FMEA

- Inputs:
  - Equipment or system/sub-system to be evaluated
  - Documentation: system specifications; equipment lists; drawings; incident history
  - Risk Matrix and Tolerability criteria
  - Failure Modes to be evaluated
  - Scenarios
- Process:
  - Evaluate response to various failure modes – causes and effects
  - Assess suitability of controls
  - Document in spreadsheet or software
- Outputs:
  - List of methods to detect failures
  - Recommendations and actions
  - Further analysis requirements

TECHNICAL STUDIES: Human Factors

- A study of the behavior of man in the organizational environment to better understand their motivations and identify the causes of errors.
- Human Factors Engineering focuses on under normal, abnormal and emergency conditions:
  - Operability: design and layout of equipment is optimised for safe, efficient, and logical access and operation
  - Maintainability: requirements for safe and efficient maintenance tasks have been incorporated into design: workspace and lay down; consideration of maintenance access and reducing work content; equipment criticality analyses
  - Access and Egress: areas of the facility, modules, and equipment can be accessed and evacuated safely and efficiently: handrails; ladders; stairs; ramps
  - Manual Materials Handling: requirements for manual lifting, pulling, pushing, and carrying of equipment, with respect for the capabilities and limitations of the personnel
  - Communication/Labelling: equipment identification and communication of operational and maintenance information: displays; alarms;
  - Environmental: working environment factors in the interests of human health, safety and performance: lighting; HVAC; noise and vibration; chemicals
  - Constructability: Ensure ease and safety of construction and installation operations.

TECHNICAL STUDIES:
Dispersion and Consequence Modelling

- INPUTS
  - Identified parameters: leak scenarios; type of risk effects; discharge – composition/volume/hole sizes/duration/direction; operating and environment conditions
  - Plot plan
  - rule sets and parameters applied for the effects of thermal radiation: vulnerability

- PROCESS (key criteria)
  - Ignition source (flammable effects including fireballs, jet fires, pool fires and flash fires.)
  - Resource manning and location
  - Equipment spacing
  - Site accommodation

- OUTPUTS
  - Contour mapping of the dispersion cloud that includes the Lower Flammable Limit (LFL) for flammable gas or concentration recommended in SDS for toxic gas
  - Contour mapping of thermal radiation and temperature/pressure profiles

TECHNICAL STUDIES: Fire & Explosion Analysis

- INPUTS
  - Accident scenario development
  - Explosion, toxic and fire hazard prediction
  - Risk and consequence evaluation
  - Hazard management near portable buildings
  - Occupancy, explosion consequence and risk screening analysis
  - Structural assessments of existing buildings for blast loads and modelling
  - Facility siting guidelines and corporate risk criteria development based on the following criteria: Operating conditions; Fluid composition; Plot plan; Weather/wind conditions
- PROCESS (key criteria)
  - Uses Consequence Modelling process
- OUTPUTS
  - Graphical display of consequence from explosion, blast, thermal radiation and fire (including smoke)

TECHNICAL STUDIES: Facilities Siting Study

- INPUTS
  - Accident scenario development
  - Explosion, toxic and fire hazard prediction
  - Risk and consequence evaluation
  - Hazard management near portable buildings
  - Occupancy, explosion consequence and risk screening analysis
  - Structural assessments of existing buildings for blast loads and modelling
  - Facility siting guidelines and corporate risk criteria development based on: Operating conditions; Fluid composition; Plot plan; Weather/wind conditions
  - Risk tolerability criteria

- PROCESS (key criteria)
  - Uses Consequence Modelling process

- OUTPUTS
  - Contour mapping of thermal radiation and temperature/pressure profiles
  - Hazardous Area Classification

TECHNICAL STUDIES:
Emergency Systems Survivability Analysis

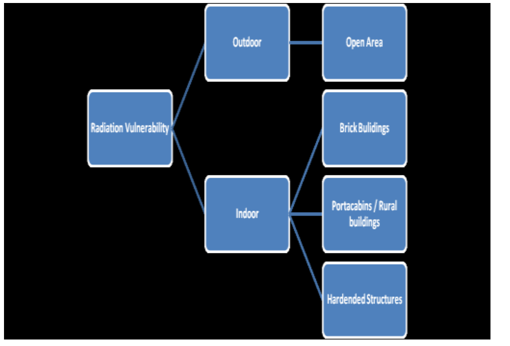
- INPUTS
  - Risk Register
  - Plot Plan and Equipment Layout
  - Impacts/Consequences

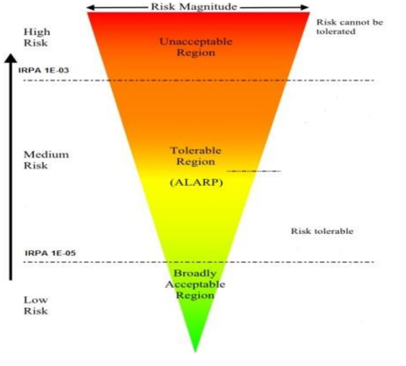
- PROCESS (key criteria)
  - Identify the controls with emergency system applicability
  - Identify critical equipment and functionality of emergency actions
  - Assess vulnerability of critical equipment to major accident events
  - Conduct qualitative risk assessment of impact severity to critical equipment
  - Document outcome Risk Register identifying any gaps and additional analyses required

- OUTPUTS
  - Identify the Emergency Systems and their required functions.
  - Identify those Emergency Systems that could be impaired by Major Accident Events
  - For these Emergency Systems, assess their ability to perform their functions during an emergency.
  - Determine whether the Emergency Systems are adequate, or make recommendations for improvement where appropriate

TECHNICAL STUDIES:
Quantitative Risk Assessment (QRA)

- INPUTS
  - Risk register
  - Risk tolerability criteria (ALARP)
  - Dispersion/Consequence Modelling
  - Fire and Explosion Analysis
  - Emergency Systems Survivability Analysis
  - Rule sets: failure frequency and ignition probability; thermal radiation and overpressure vulnerability; process, occupational, transportation and societal risks
- PROCESS (key criteria)
  - Assess facility layout and population exposure
  - Apply frequency and consequence analysis
- OUTPUTS
  - Risk contours and/or Frequency/Number fatality (FN) graphs
  - Individual risk per annum (IRPA)
  - Potential loss of life (PLL)





Risk Region	IRPA Most Exposed Person	LSIR (At Facility Boundary)	Treatment of Risk
Intolerable Risk	$> 1 \times 10^{-3}$	$> 1 \times 10^{-4}$	A level of risk that is so high as to require significant and urgent actions to reduce its magnitude. If these risk levels cannot be reduced to ALARP or tolerable level, the project objectives and operating philosophy must be fundamentally reviewed by the management.
ALARP Region	$1 \times 10^{-5} < \text{IRPA} < 1 \times 10^{-3}$ Goal New Facilities $< 5 \times 10^{-4}$	$1 \times 10^{-6} < \text{LSIR} < 1 \times 10^{-4}$	Efforts must be made to reduce risk further, and as far as can be achieved without the expenditure of a cost that is grossly disproportionate to benefit gained.
Tolerable	$<1 \times 10^{-5}$	$<1 \times 10^{-6}$	A level of risk that is so low as to not require actions to reduce its magnitude further, but which will be monitored and managed by the site using its management system.

Source: CCPS publications; UKHSE

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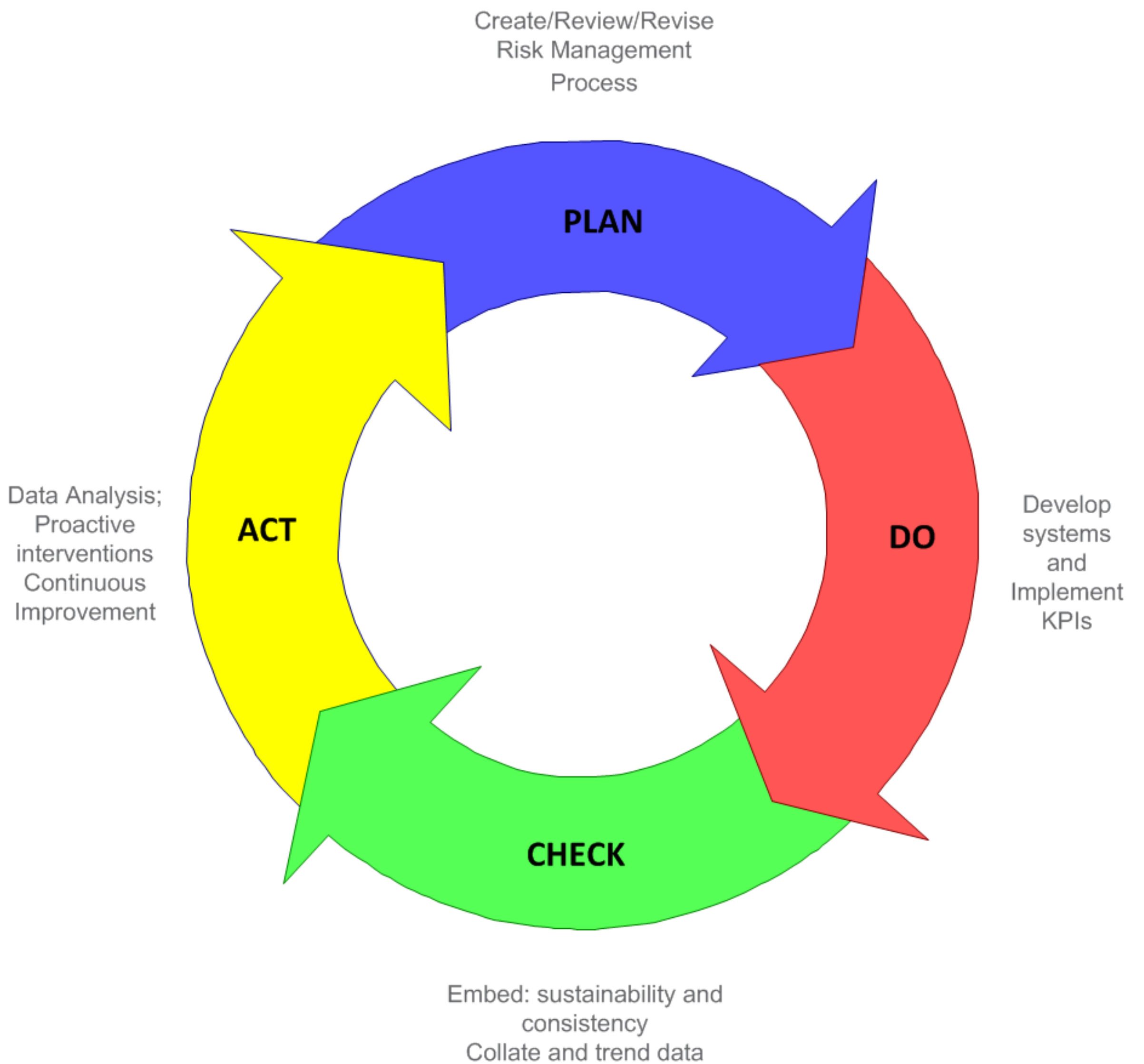
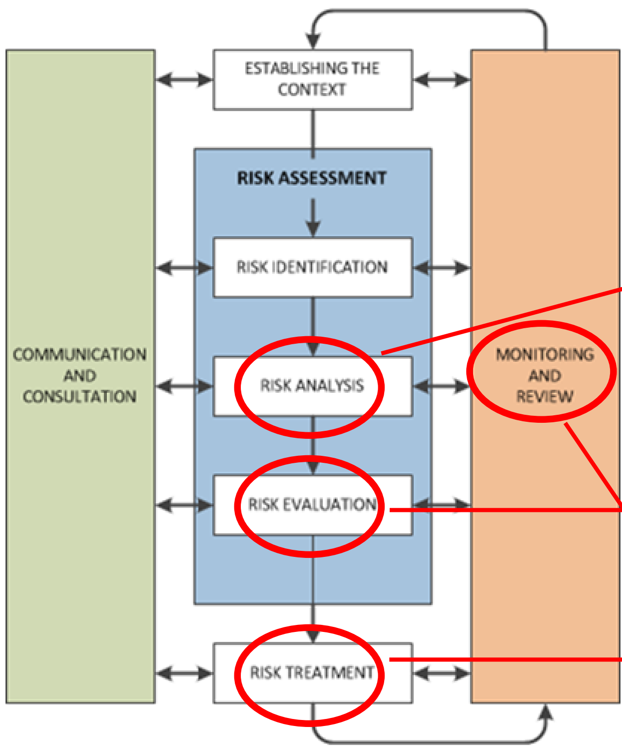
Governance and Assurance: Sustainability Model



Governance and Assurance: Baseline



Baseline:

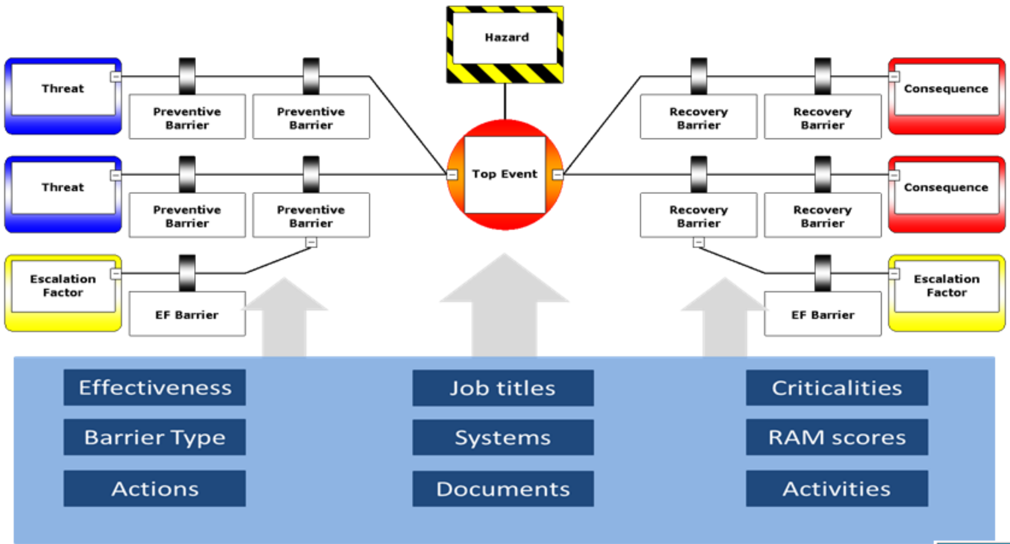
- Using the Company's Risk Matrix based on:
  - Severity Levels for Inherent Risk (no controls)
  - Likelihood Factors and Severity for Residual Risks (effective controls)
  - For all relevant Impact Categories

  - Apply Tolerability Criteria
  - Classify and Rank Risks

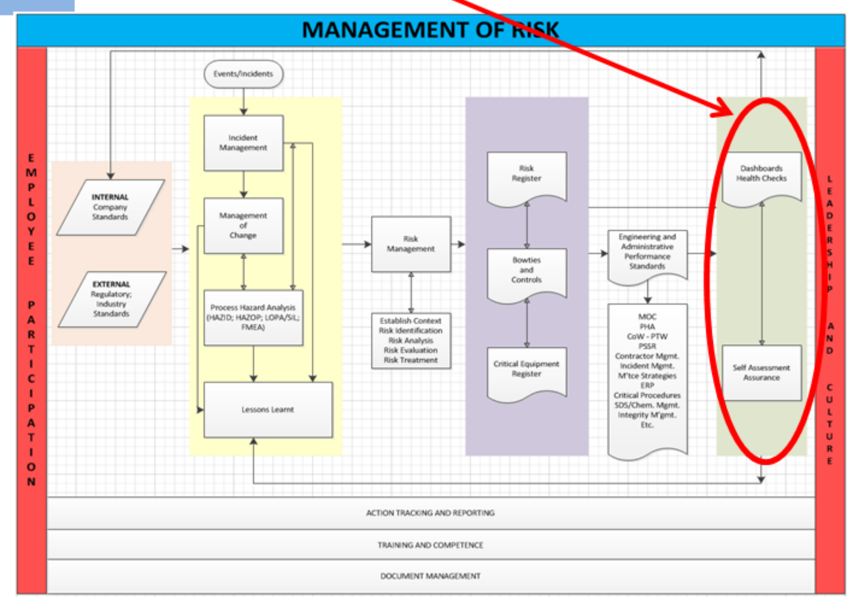
- Identify and implement improvement actions

- Documented in the Risk Register, inclusive of justifications/details

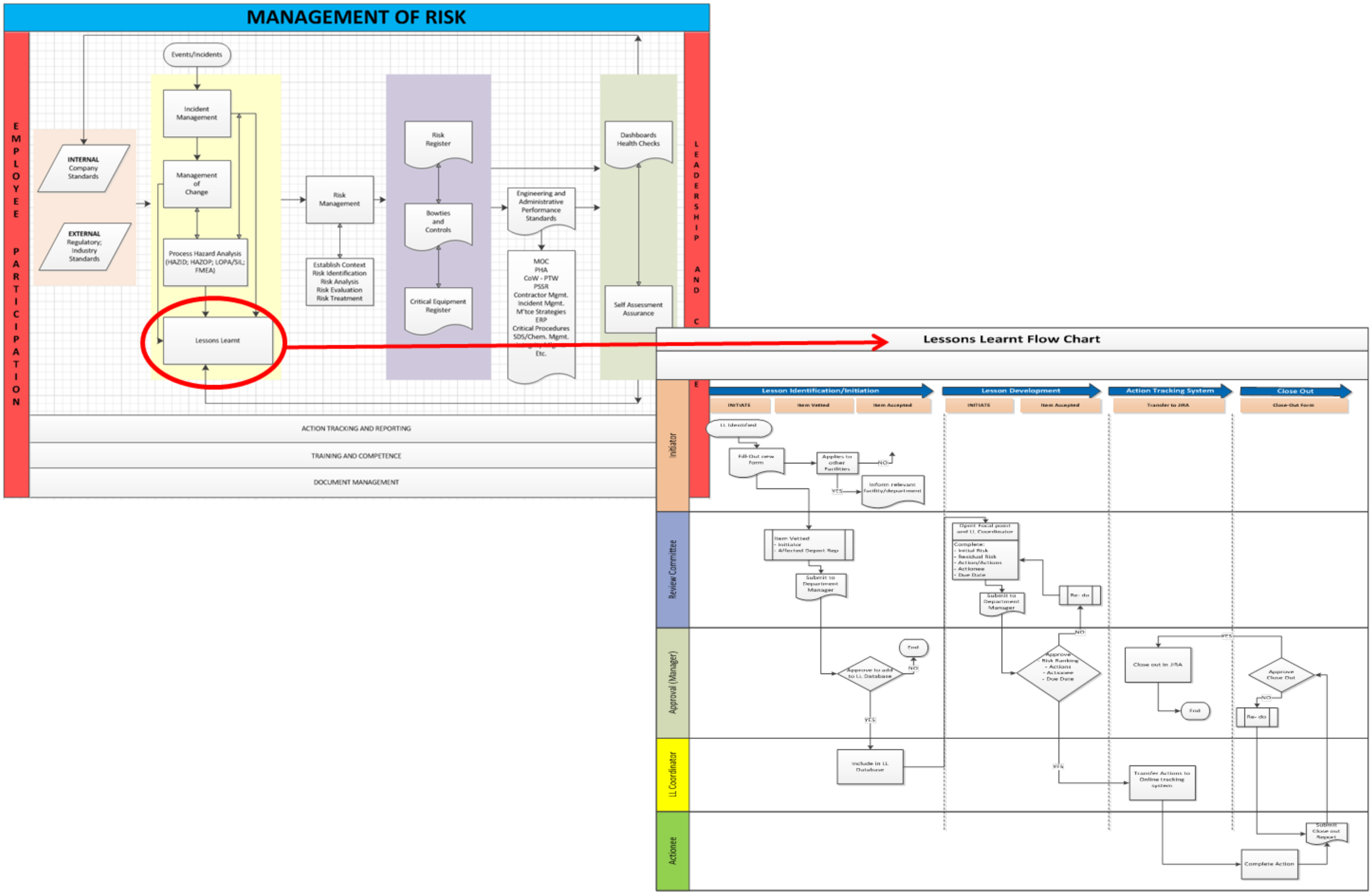
Governance and Assurance: Review and Verification



Source: CGE publications



Governance and Assurance: Lessons Learnt



Conclusions and Summary:

- Compliance is not driven only by regulatory requirements: it is a Core Value
- Profitability is a function of how risk is understood and managed
- The life cycle of “Management of Risk” and the interdependencies need to be understood and applied
- Selection of risk assessment methodology is driven by objectives/goals. No one PHA is applicable.
- Process Hazard Analyses are applicable from cradle to grave
- Technical Studies are critical to understanding the risk impacts
- Sustainability is essential to continuous improvement
- Establishing risk tolerability criteria provide the bases for assessments
- Baselines provide the opportunity to determine deviations

Risk Assessments and Risk Models are an ongoing process