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After the Hazard Analysis:
Semi-Quantitative Risk Analysis to Derive Controls Using Layer of Protection Analysis

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ExxonMobil Refinery Explosion

- ExxonMobil Refinery Explosion
  - Torrance, CA 2015
  - https://youtu.be/JplAKJrgyew

http://www.csb.gov/mobile/videos/animation-of-2015-explosion-at-exxonmobil-refinery-in-torrance-ca/

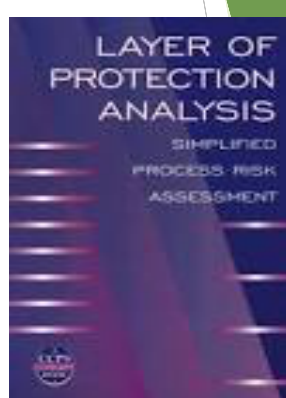
Discussion

- [ExxonMobil Refinery Explosion](https://youtu.be/JplAKJrgyew)
  - Controls
  - Assignment of Values
  - Hierarchy Analysis
  - https://youtu.be/JplAKJrgyew

http://www.csb.gov/mobile/videos/animation-of-2015-explosion-at-exxonmobil-refinery-in-torrance-ca/

Layer of Protection Analysis (LOPA)

- LOPA History
- LOPA Defined
- LOPA Common Elements
- LOPA Use – Motivating Factors
- LOPA Steps
- LOPA Limitations/Benefits
- LOPA References



LOPA History

- Origin with Company Specific Development
- Parallel Development of Safety Integrity Levels (SIL)
- Multiple Papers Published ~ 1997
- Center for Chemical Process Safety
  - Internal Conference ~ 1997
  - Workshop ~ 2000
  - LOPA Concept Book ~ 2001
  - "Redbook" Incorporation ~ 2008

LOPA Purpose

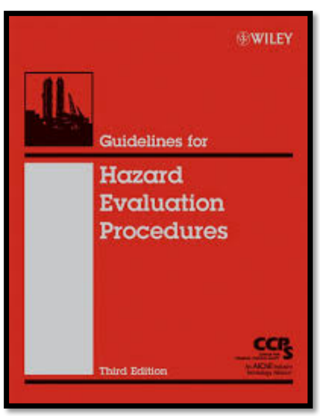
- Replace Quantitative Risk Assessment
- Determine if Sufficient Layers of Controls
- Use of LOPA as Semi Quantitative Hazard Evaluation Tool for Judging Risk of Accident Scenarios
- Risk Analysis Tool that Must be Applied Correctly

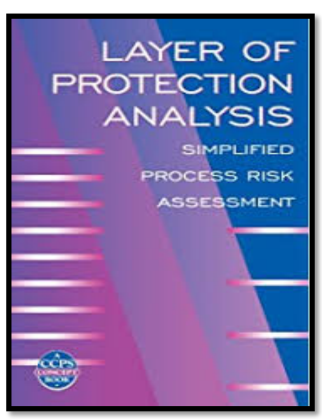
LOPA Defined

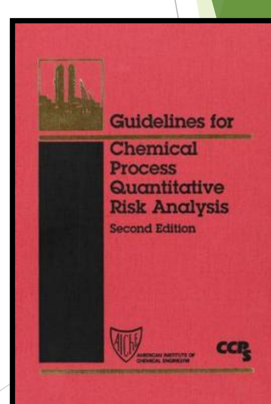
- Simplified Method of Risk Assessment
  - Semi-Qualitative
  - Semi-Quantitative
  - Intermediate Between Qualitative and Quantitative
- Simplified Rules to Evaluate Scenario Impacts
  - Initiating Cause Frequency
  - Independent Layers of Protection
- Provide Order of Magnitude Risk Estimate

Layer of Protection Analysis

Qualitative vs Quantitative







LOPA Defined

- Qualitative Hazard Evaluation Techniques
  - Generalized Cause – Consequence, Loss Events, and Assignment of Preventative or Mitigative Controls
- Quantitative Hazard Evaluation Techniques
  - Assigned Failure Rates for Equipment/Controls Using Ever Increasing Detail for Site/Industry
- Layer of Protection Analysis
  - Order of Magnitude Estimates of Cause Frequency & Control Effectiveness
  - Control Effectiveness = Independent Layers of Protection (IPL)

LOPA Defined

- Traditional Hazards Analysis Looks at Entire System or Process
  - Qualitative – What If, What-If/Checklist, HazOp
  - Quantitative – Fault Tree, Event Tree, QRA
- LOPA Looks at Individual Scenario
- Applied After Traditional Methods
  - Narrow Focus on Important Events
  - Derived Significant Controls

LOPA Defined

- Simplified Form of Risk Assessment
- Order of Magnitude Categories
  - Event Frequency
  - Consequence Severity
  - Likelihood of Failure of Independent Protection Layers (IPL)
- Builds On Qualitative Hazards Analysis ~ Semi Quantitative/Qualitative
- Rule-Based Implementation

Common Elements

- Consequence Classification Method
  - Typically Company Specific
  - Use of Standard Consequence Table
  - Derived from Qualitative HE
- Numerical Risk Tolerance Criteria
  - Fatalities & Fire Frequencies
  - Required Number of IPL Credits
  - Maximum Frequency for Specified Categories
- Method of Developing Scenarios

Common Elements

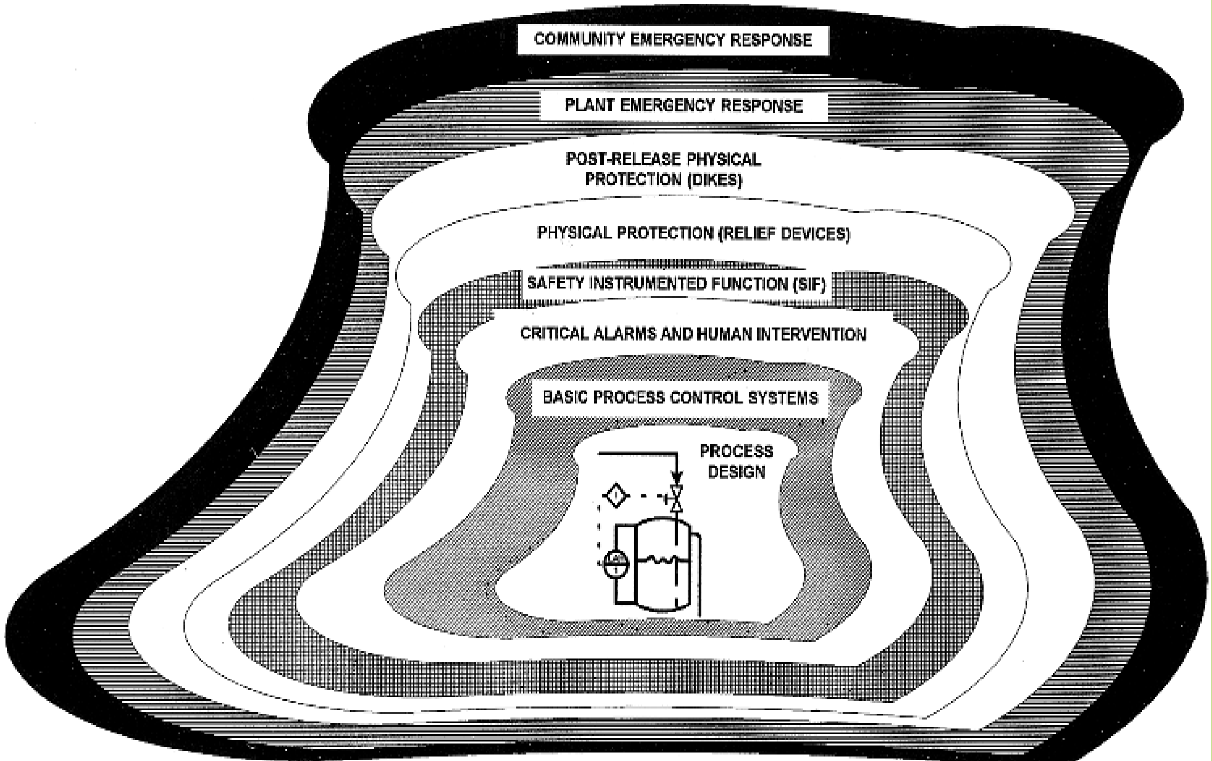
- Rules for Controls as IPLs
- Default Frequency Data
  - Event Frequencies
  - Credits for IPLs
- Procedure for Calculation
- Procedure for Application/Acceptance

- Rules for Controls as IPLs
  - Independence
  - Functionality
  - Integrity
  - Reliability
  - Auditability
  - Access Security
  - Management of Change

LOPA Use

- Effectively Used Throughout Safety Life Cycle
- Preferred Use
  - Detailed Design Stages
  - Modifications to Designs
- Techniques Where Defining
  - Control Hierarchy
  - Control Requirements
- Use for Engineering/Administrative Controls

Defense in Depth



Ref. Center for Chemical Process Safety, *Layer of Protection Analysis: Simplified Process Risk Assessment*

LOPA Use

- Typically Performed After Analyzing System with Qualitative Hazard Evaluation (HE) Technique
- Higher Risk Scenario
  - Decision Quality Requires Increased Clarity
- Risk = Frequency x Consequence
  - Higher Consequence Requires Higher Confidence to Support Decision Making
  - Narrowed Focus on Frequency Control
- LOPA Uses Common Conservative Frequency and Control Effectiveness Values to Derive Acceptable Risk for a Given Scenario

LOPA Use

- LOPA is a Process to Evaluate Risk with Explicit Risk Tolerance for Specific (Higher) Consequences
- Support Rationale "Risk Based" Business Decisions
- Creating Value without Taking Unnecessary Risk
- Tolerable Frequency is Decision Criterion for Design and Operational Changes

Use of LOPA

- Tolerable Frequency is Decision Criteria for Design and Operational Changes
- Allocate Proportionate Resources Commensurate with Risk
- Higher Consequence – Lower Tolerable Frequency
- Acceptable Risk = Risk Tolerance
- Company Decisions Based On Risk Tolerance

LOPA Steps

- Step 1 – Analyze Single Event/Consequence
  - Specific Hazard, Receptor, & Consequence
- Step 2 – Determine Tolerable Frequency
- Step 3 – Assess Probability of Initiating Events
- Step 4 – Identify Independent Protection Layers (IPLs)
- Step 5 – Calculate Expected Frequency
  - Initiating Event x Failure of Safeguards
- Step 6 – Determine Safeguards
- Step 7 - Determine Residual Risk
- Step 8 – Apply Safeguards Until Acceptable Risk

LOPA Worksheet

LOPA Worksheet

Facility:		Date:	
Process:			
Equipment ID:	Equipment Reference:		
Analyst(s):			
Scenario Number:	Scenario Description:	Hazard(s):	
Item	**Description**	**Probability**	**Frequency (per year)**
Consequence			
Initiating Event			
Enabling Event or Condition			
Conditional Modifiers (if applicable)	Probability of ignition		
	Probability of personnel in affected area		
	Probability of fatal injury		
	Others		
Frequency of Unmitigated Consequence			
Independent Protection Layers			
Safeguards (non-IPLs)			
Total PFD for all IPLs			
Frequency of Mitigated Consequece			
Risk Tolerance Criteria:			
Actions Required:			
Referencees:			
Quality Review:			
Notes:			

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LOPA Steps

- Event Side
  - Identify Unacceptable Consequence
  - Screen Events Against Consequence
  - Determine Event Frequency
- Control Side
  - Identify IPLs
  - Identify Probability of IPL Failure
  - Add Controls to Tolerable Risk
- Event Side – Control Side = Residual Risk
- Event Side – Control Side = Acceptable Risk

Failure Rates

- Standard Industry Values
- Standard Corporate Values
  - Comparable
  - Common Risk Decisions

TABLE 5.1
Typical Frequency Values, f^I, Assigned to Initiating Events

Initiating Event	Frequency Range from Literature (per year)	Example of a Value Chosen by a Company for Use in LOPA (per year)
Pressure vessel residual failure	10^{-5} to 10^{-7}	1×10^{-6}
Piping residual failure—100 m—Full Breach	10^{-5} to 10^{-6}	1×10^{-5}
Piping leak (10% section)—100 m	10^{-3} to 10^{-4}	1×10^{-3}
Atmospheric tank failure	10^{-3} to 10^{-5}	1×10^{-3}
Gasket/packing blowout	10^{-2} to 10^{-6}	1×10^{-2}
Turbine/diesel engine overspeed with casing breach	10^{-3} to 10^{-4}	1×10^{-4}
Third party intervention (external impact by backhoe, vehicle, etc.)	10^{-2} to 10^{-4}	1×10^{-2}
Crane load drop	10^{-3} to 10^{-4} per lift	1×10^{-4} per lift
Lightning strike	10^{-3} to 10^{-4}	1×10^{-3}
Safety valve opens spuriously	10^{-2} to 10^{-4}	1×10^{-2}
Cooling water failure	1 to 10^{-2}	1×10^{-1}
Pump seal failure	10^{-1} to 10^{-2}	1×10^{-1}
Unloading/loading hose failure	1 to 10^{-2}	1×10^{-1}
BPCS instrument loop failure *Note:* IEC 61511 limit is more than 1×10^{-5}/hr or 8.76×10^{-2}/yr (IEC, 2001)	1 to 10^{-2}	1×10^{-1}
Regulator failure	1 to 10^{-1}	1×10^{-1}
Small external fire (aggregate causes)	10^{-1} to 10^{-2}	1×10^{-1}
Large external fire (aggregate causes)	10^{-2} to 10^{-3}	1×10^{-2}
LOTO (lock-out tag-out) procedure* failure *overall failure of a multiple-element process	10^{-3} to 10^{-4} per opportunity	1×10^{-3} per opportunity
Operator failure (to execute routine procedure, assuming well trained, unstressed, not fatigued)	10^{-1} to 10^{-3} per opportunity	1×10^{-2} per opportunity

Note: Individual companies should choose their own values, consistent with the degree of conservatism of the company's risk tolerance criteria. Failure rates can also be greatly affected by preventive maintenance (PM) routines

Ref. Center for Chemical Process Safety, *Layer of Protection Analysis: Simplified Process Risk Assessment*

Independent Protection Layer

- Independent from the Initiating Event
- Independent from other IPLs/Safeguards

LOPA IPL Values

- Standard Industry Values
- Standard Corporate Values
  - Comparable
  - Common Risk Decisions

can be credited as IPLs with a high level of confidence and will significantly reduce the frequency of events with potentially major consequences. However, there may be other, less serious consequences (such as a fire in dike, blast damage to some equipment) that should be analyzed in other scenarios.

Fireproofing is a means of reducing the rate of heat input to equipment (e.g., when considering the sizing basis for relief valves, for preventing a boil-

TABLE 6.3
Examples of Passive IPLs

IPL	Comments *Assuming an adequate design basis and adequate inspection and maintenance procedures*	PFD from Literature and Industry	PFD Used in This Book (For screening)
Dike	Will reduce the frequency of large consequences (widespread spill) of a tank overfill/rupture/spill/etc.	$1 \times 10^{-2} - 1 \times 10^{-3}$	1×10^{-2}
Underground Drainage System	Will reduce the frequency of large consequences (widespread spill) of a tank overfill/rupture/spill/etc.	$1 \times 10^{-2} - 1 \times 10^{-3}$	1×10^{-2}
Open Vent (no valve)	Will prevent over pressure	$1 \times 10^{-2} - 1 \times 10^{-3}$	1×10^{-2}
Fireproofing	Will reduce rate of heat input and provide additional time for depressurizing/firefighting/etc.	$1 \times 10^{-2} - 1 \times 10^{-3}$	1×10^{-2}
Blast-wall/Bunker	Will reduce the frequency of large consequences of an explosion by confining blast and protecting equipment/buildings/etc.	$1 \times 10^{-2} - 1 \times 10^{-3}$	1×10^{-3}
"Inherently Safe" Design	If properly implemented can significantly reduce the frequency of consequences associated with a scenario. Note: the LOPA rules for some companies allow inherently safe design features to eliminate certain scenarios (e.g., vessel design pressure exceeds all possible high pressure challenges).	$1 \times 10^{-1} - 1 \times 10^{-6}$	1×10^{-2}
Flame/Detonation Arrestors	If properly designed, installed and maintained these should eliminate the potential for flashback through a piping system or into a vessel or tank.	$1 \times 10^{-1} - 1 \times 10^{-3}$	1×10^{-2}

Ref. Center for Chemical Process Safety, *Layer of Protection Analysis: Simplified Process Risk Assessment*

Benefits

- Simplified Framework for Understanding Risk
- Defensible Process/Procedure
- Less Time Than Quantitative Risk Analysis
- Defines Safety Integrity Levels
- Defines Hierarchy of Controls
- Means of Comparing Risk

Limitations

- Internal Risk Comparisons Valid Only When Using Same LOPA Method
- Result Values Are Not Precise
- Should Not Be Applied to All Scenarios
- Time/Resource Commitment
- Not Hazard Identification/Evaluation Tool
- External Risk Comparisons Not Typically Valid

References

- Guidelines for Hazard Evaluation Procedures, 3rd Ed; CCPS 2008
- Layer of Protection Analysis: Simplified Process Risk Assessment; CCPS 2001
- Guidelines for Initiating Events and Independent Layers of Protection Analysis, 1st Ed; CCPS 2014
- Guidelines for Enabling Conditions and Conditional Modifiers in Layer of Protection Analysis; CCPS 2015
- Layer of Protection Analysis; PII 2014

Follow Up with Parvati

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- Facility/Worker/Nuclear Safety & Safety Basis
  - Redbook Training
    - Redbook Overview
    - Redbook HE Techniques
      - What-If/Checklist
      - Failure Modes & Effects Analysis (FMEA)
      - Hazard & Operability Analysis (HazOp)
      - Layer of Protection Analysis (LOPA)
      - Risk Analysis
      - Inherent Safety Reviews
  - Perform Process Hazards Analysis
  - Compliance Auditing & Readiness
  - Hazard Evaluation Facilitation
  - Peer Review PHA (HI + HE)
  - Integration Techniques
  - Systems Theoretic Accident Model and Processes Analysis (STAMP)/ Systems Theoretic Process Analysis (STPA)
- Traditional ES&H/IH/OS Services


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