IST Concepts and Methodologies for Implementation

Inherently Safer Technology Workshop
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He is a frequent speaker on security, process safety management, human factors, and inherent safety for the petroleum and chemical industry. His firm is actively involved in chemical process security and safety consulting and training. He has provided risk consulting services and training to industrial facilities worldwide, including oil refineries, chemical plants, pipelines, and manufacturing plants. Mr. Moore has taught process safety and security courses for over 15 years to many of the world's largest corporations. He is an instructor on process safety and security for AIChE, API, OSHA, USEPA, and the NPRA.

Mr. Moore was formerly a Senior Engineer with Mobil Corporation; and a Fire Protection Engineer with the National Fire Protection Association. He has been consulting in the industry since 1987.

Mr. Moore is a Registered Professional Engineer. He serves on the AIChE Center for Chemical Process Safety Technical Steering Committee, the CCPS Plant Security Committee, the Canadian Chemical Producer's Association PSM Committee, and the Mary Kay O'Connor Process Safety Center at Texas A&M University. He has an MBA, (NYU-1987), and a B.Sc., Fire Protection Engineering (University of Md.-1979).

Inherent Safety Status

- Industry:
  - IS is gaining popularity as a process risk management strategy but is not universally practiced or documented
- Government
  - Recent proposed safety and security regulations are focusing on IS as a first choice strategy for risk reduction

Definition of Inherently Safer Systems

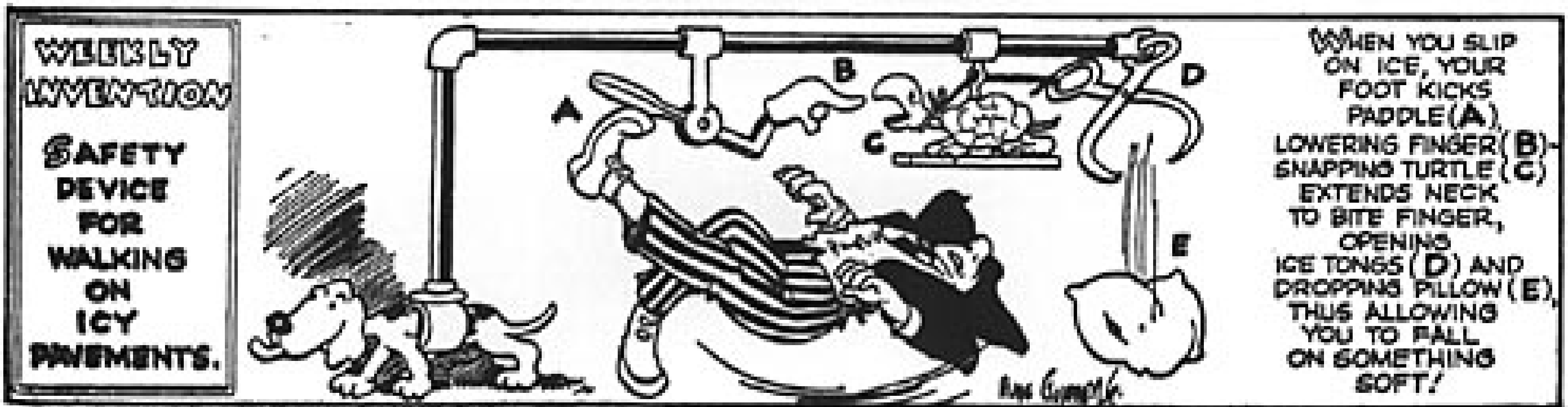
- The term inherently safer implies that the process is safer because of its very nature and not because equipment has been added to make it safer.[1]

[1] Process Plants: A Handbook for Safer Design, 1998, Trevor Kletz."

“Inherent” Definition

- Existing as a natural or basic part of something (Cambridge Dictionary)
- Existing in something as a permanent and inseparable element, quality, or attribute (American College Dictionary)
- Involved in the constitution or essential character of something : belonging by nature or habit (Merriam Webster)

Not So Inherent Safety



RUBE GOLDBERG (TM) RGI 100

Inherently Safer Design (ISD)

- A concept of eliminating or reducing hazards to reduce risk through the application of strategic principles of:
  - Minimization
  - Substitution
  - Moderation
  - Simplification

Basic Premise of Inherently Safer Design

- It may not be feasible to completely eliminate hazards, but still can be useful to reduce hazards
- The reduction of hazards should be the first priority
- The concept should be practiced by engineers, operations, maintenance personnel, not only by safety personnel
- ISD opportunities should be analyzed at regular intervals or project milestones, and in daily decisions
- While most potent for new facilities, it is also useful and practical for existing facilities

Inherent Safety Status

- Process safety professionals have embraced the concepts voluntarily for years;
- It is an established method for addressing process risks;
- In balance with other risk management strategies it has a significant place.

ISD Background

- Recognized in 1970's for chemical industry – T. Kletz, "What You Don't Have Can't Leak"
- 1996: CCPS Concept Book- "Inherently Safer Chemical Processes- A Life Cycle Approach"
- 1980-2008 - Practiced by many leading companies
- Future – More widely practiced as core business principle

Applications of Inherently Safer Design

- Applications are wide-ranging including use a corporate philosophy for reducing risks associated with:
  - Process safety
  - Environmental releases
  - Security
  - Operational upsets
  - Reliability problems
- Proven to have been feasible in some cases and to reduce potential likelihood and consequences of events

Inherently Safer Design Strategies

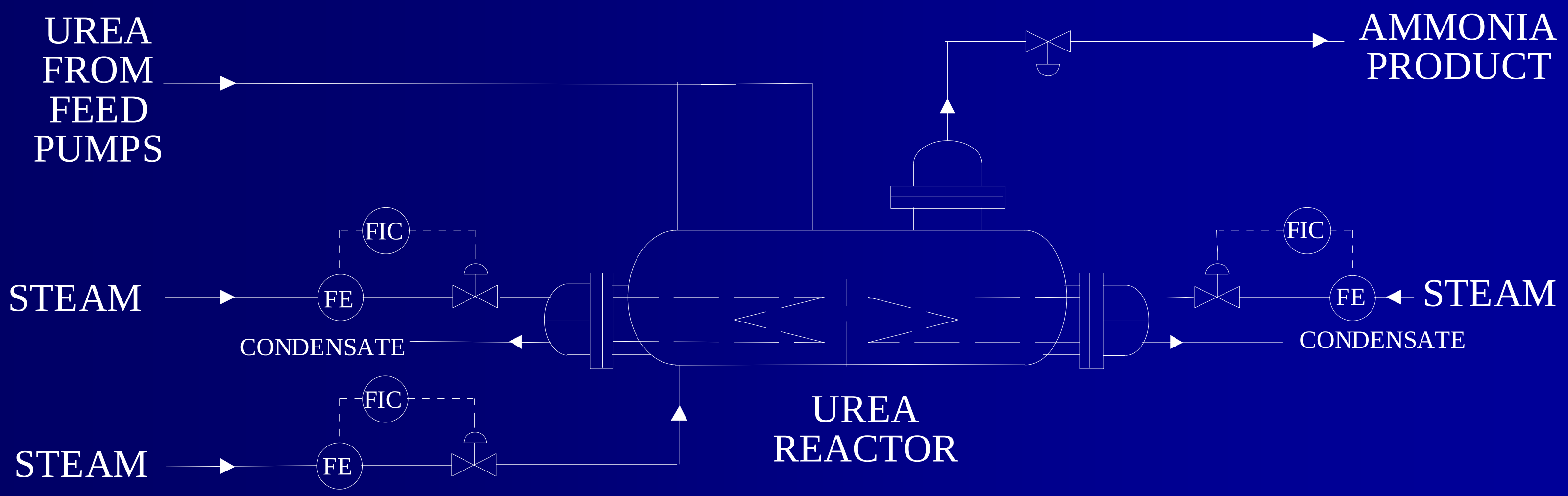
Strategy	Examples
Minimize	Use smaller quantities; eliminate unnecessary equipment; reduce size of equipment or volumes processed.
Substitute	Replace material with a less hazardous substance.
Moderate	Use less hazardous conditions, a less hazardous form of material or facilities which minimize the impact of a release.
Simplify	Design facilities which eliminate unnecessary complexity and make operating errors less likely.

Inherent Safety Viewpoints

Viewpoint	Examples
Macro	• Use alternative technology that has a lower operating pressure • Substitute feedstocks with less toxic substance • Substitute entire process
Micro	• Reduce the size of a particular vessel or line in a process • Use a catalyst that is less toxic • Simplify DCS controls

Market-Driven Inherent Safety

SafeDeNOx® Reactor System



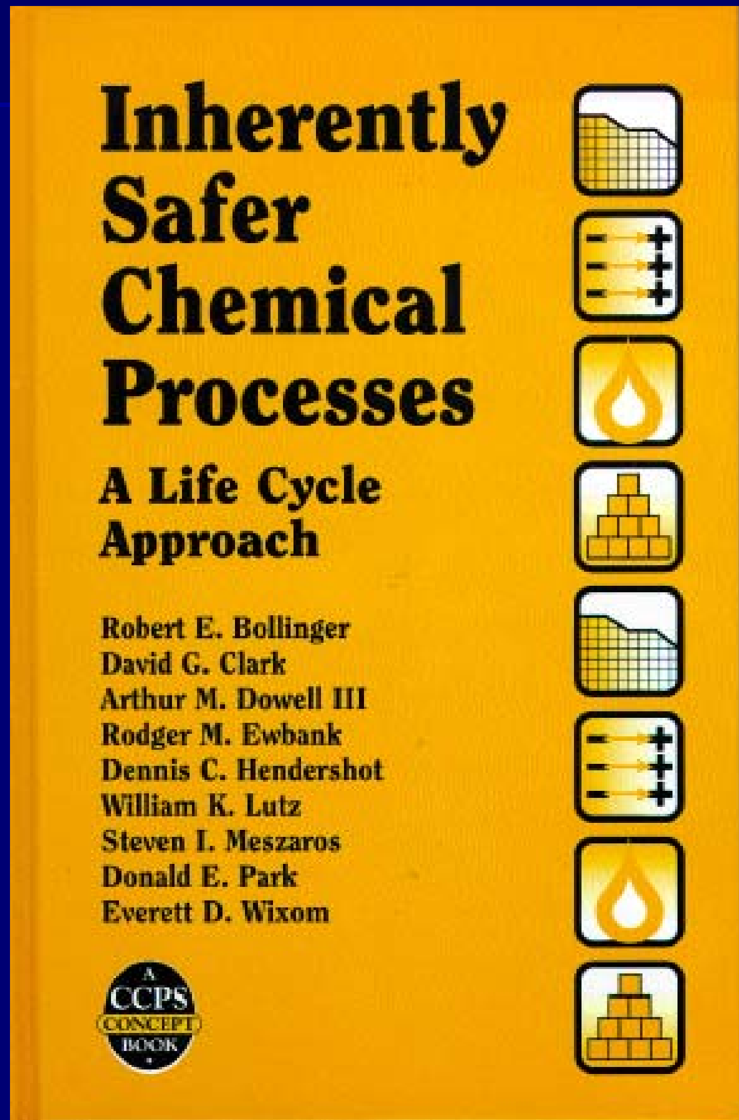
Overall reaction

$$(NH_2)_2CO + H2O \rightarrow CO_2\uparrow + 2NH_3\uparrow$$

Urea + water vapor carbon dioxide + ammonia

American Institute of Chemical Engineers
Center for Chemical Process Safety
Concept Book (1996)

‘The Gold Book’
Of CCPS



Inherent Safety Concept Book Update

- CCPS "Inherently Safer Chemical Process, A Life Cycle Approach, 1st Ed. (1996) updated in 2006-8;
- 2nd Edition to be published in mid 2008
- Update prompted by:
  - lessons learned and developments since then
  - inherently safer design (ISD) becoming more widely accepted
- Need for more guidance due to
  - new regulations with requirements for ISD
  - lack of clarity on how to practically implement

Objectives & Scope of Update

- Goal of updated book is to illustrate and emphasize merits of integrating process research, development & design into a comprehensive process balancing safety, capital, and environmental concerns throughout life cycle of process;
- Primary objective is to provide useful tool for any company to understand and employ inherent safety concepts;
- Secondary objective to provide tools and guidance on approaches to implement inherent safety.

Achievements of Updated Concept Book

- Clarified concepts with recent research;
- Introduced new concept of 1st and 2nd orders of Inherently Safer Design (ISD);
- Added examples for each ISD strategy and order;
- Included illustrations of applying ISD across entire life cycle of process;
- New and more complete inherently safer checklist;
- Practical methods of applying ISD to a process & analyzing hazards & opportunities for risk reduction (enhanced PHA methods);
- Included homeland security issues and regulatory issues.

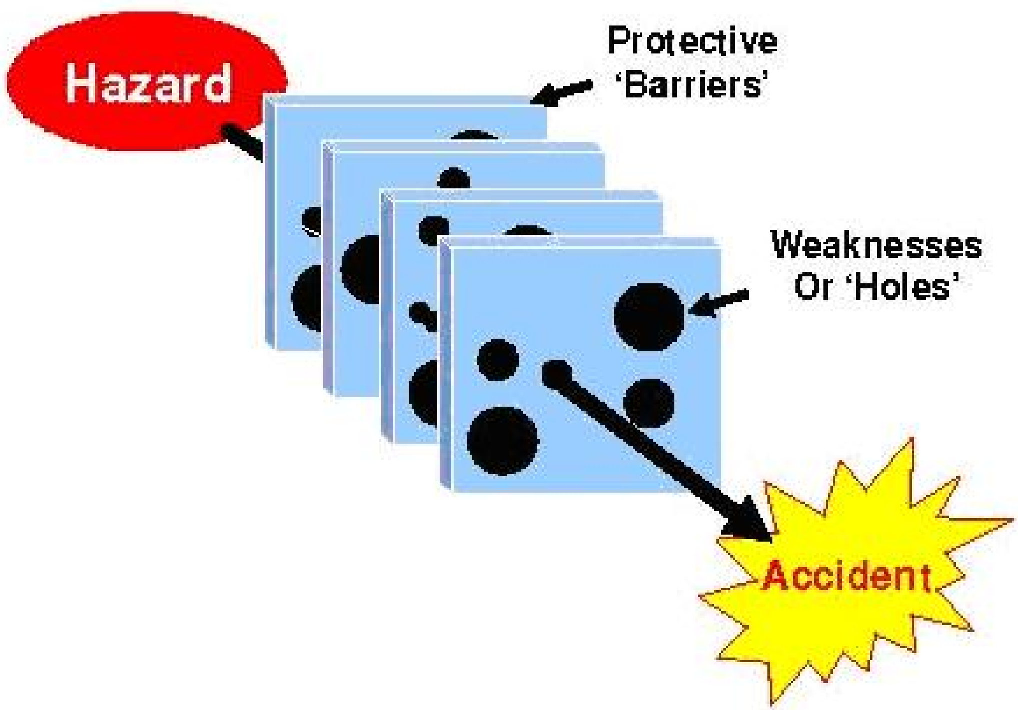
What is Inherently Safer Technology (IST?)

"principles or techniques incorporated in a covered process to minimize or eliminate the potential for an extraordinarily hazardous substance (EHS) accident that include, but are not limited to, the following:

1. Reducing the amount of EHS material that potentially may be released
2. Substituting less hazardous materials
3. Using EHSs in the least hazardous process conditions or form
4. Designing equipment and processes to minimize the potential for equipment failure and human error"

Source: NJ Prescriptive Order 11/21/05

Accident Sequence



Risk-Based Approach for Safety Risk Assessment

Step 1
Hazard Identification

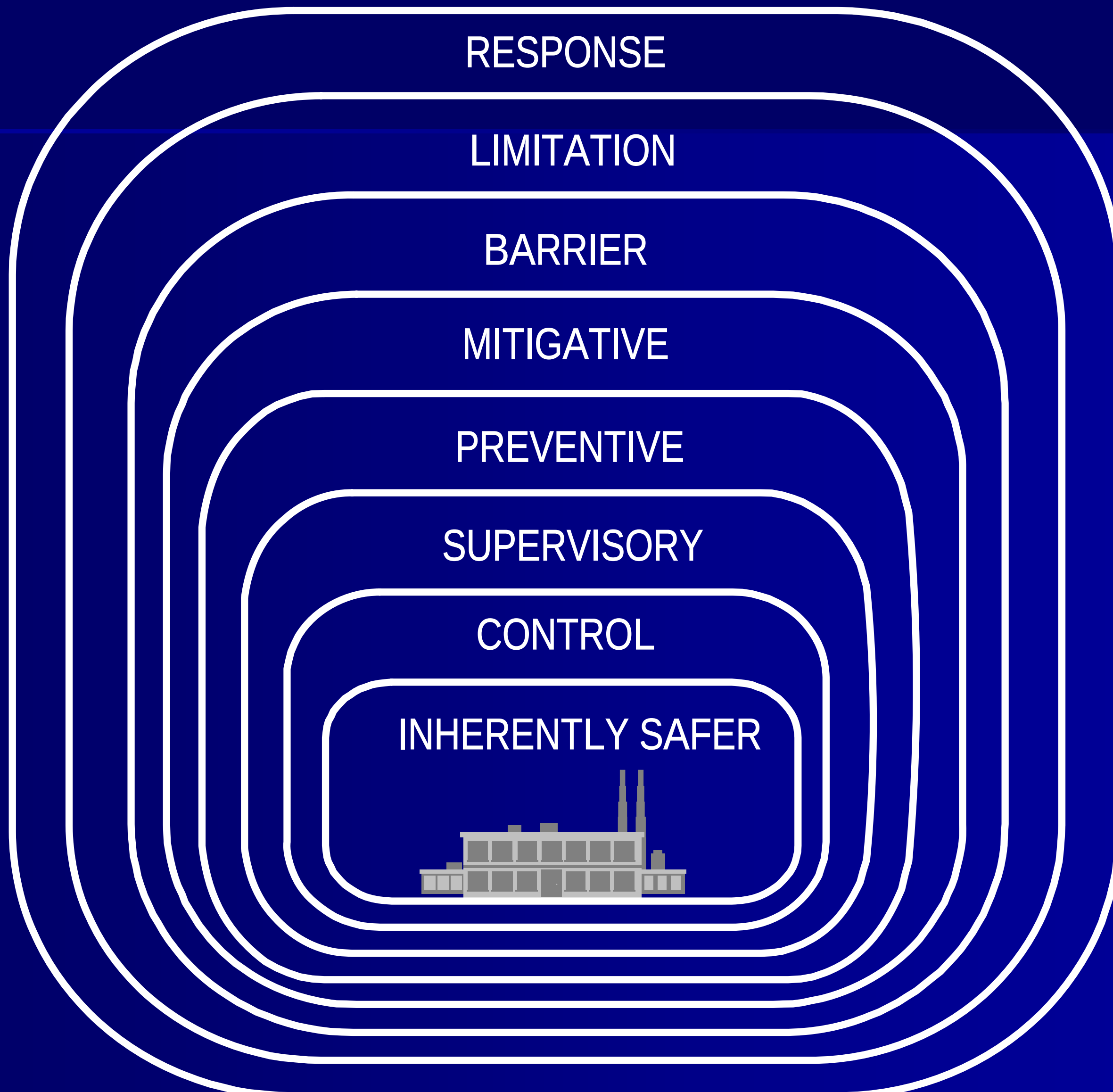
Step 2
Consequence and Impact Analysis

Step 3
Likelihood Analysis

Step 4
Risk Assessment

Step 5
Mitigation Analysis

Layers Of Protection



Process Safety Strategies

- Inherent
  - Eliminate or modify the hazard and/or risk by employing one of four strategies of substitution, minimization, moderation, simplification.
- Passive
  - Minimize the hazard by process and equipment design features which reduce either the frequency or consequences of the hazard without the active functioning of any device.
- Active
  - Using controls, safety interlocks, and emergency shutdown systems to detect and correct process deviations.
- Procedural
  - Using operating procedures, administrative checks, and emergency response to prevent incidents, or to minimize the effect of an incident.

Source: CCPS

Inherently Safer Technology Strategies

Strategy	Examples
Substitute	Replace material with a less hazardous substance.
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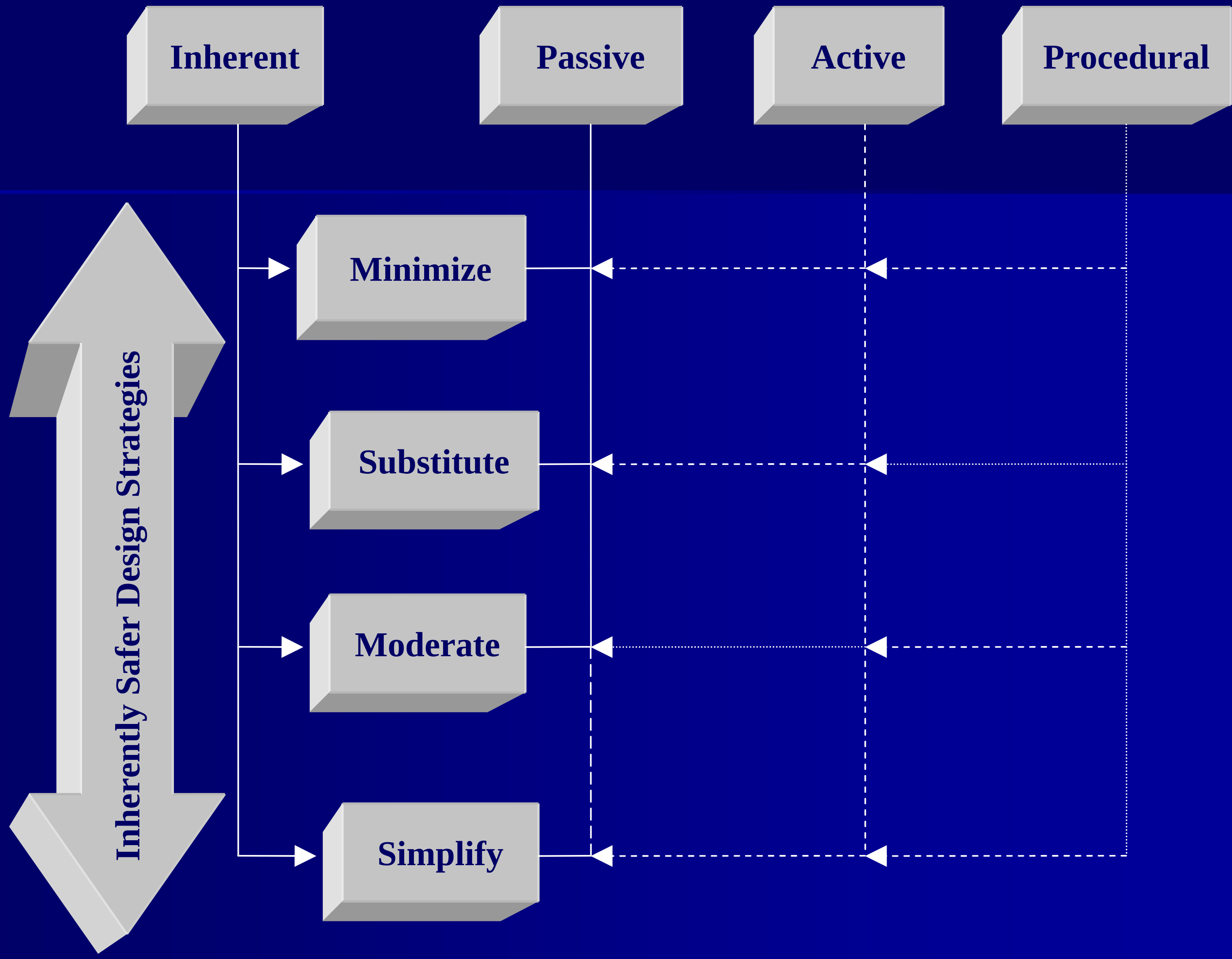
Moderate	Use less hazardous conditions, a less hazardous form of material or facilities which minimize the impact of a release.
Simplify	Design facilities which eliminate unnecessary complexity and make operating errors less likely.

Process Risk Management Strategies



Source: Fig 2.2, CCPS Concept Book

Substitution

- Substitute a less hazardous reaction chemistry
- Replace a hazardous material with a less hazardous alternative

Minimization

- Use small quantities of hazardous substances or energy
  - Storage
  - Intermediate storage
  - Piping
  - Process equipment

Moderation

Reduce temperatures or pressures

- Dilution
- Refrigeration
- Less severe processing conditions
- Physical characteristics
- Containment
  - Better described as “passive” rather than “inherent”

Simplification

- **Eliminate unnecessary complexity to reduce risk of human error**

QUESTION ALL COMPLEXITY!

Is it really necessary?

Which Strategy Should We Use?

- Generally, in order of robustness and reliability:
  - Inherent
  - Passive
  - Active
  - Procedural
- But - there is a place and need for ALL of these strategies in a complete safety program

Figure 1: Inherently Safer Approach to Analyzing & Managing Process Risks

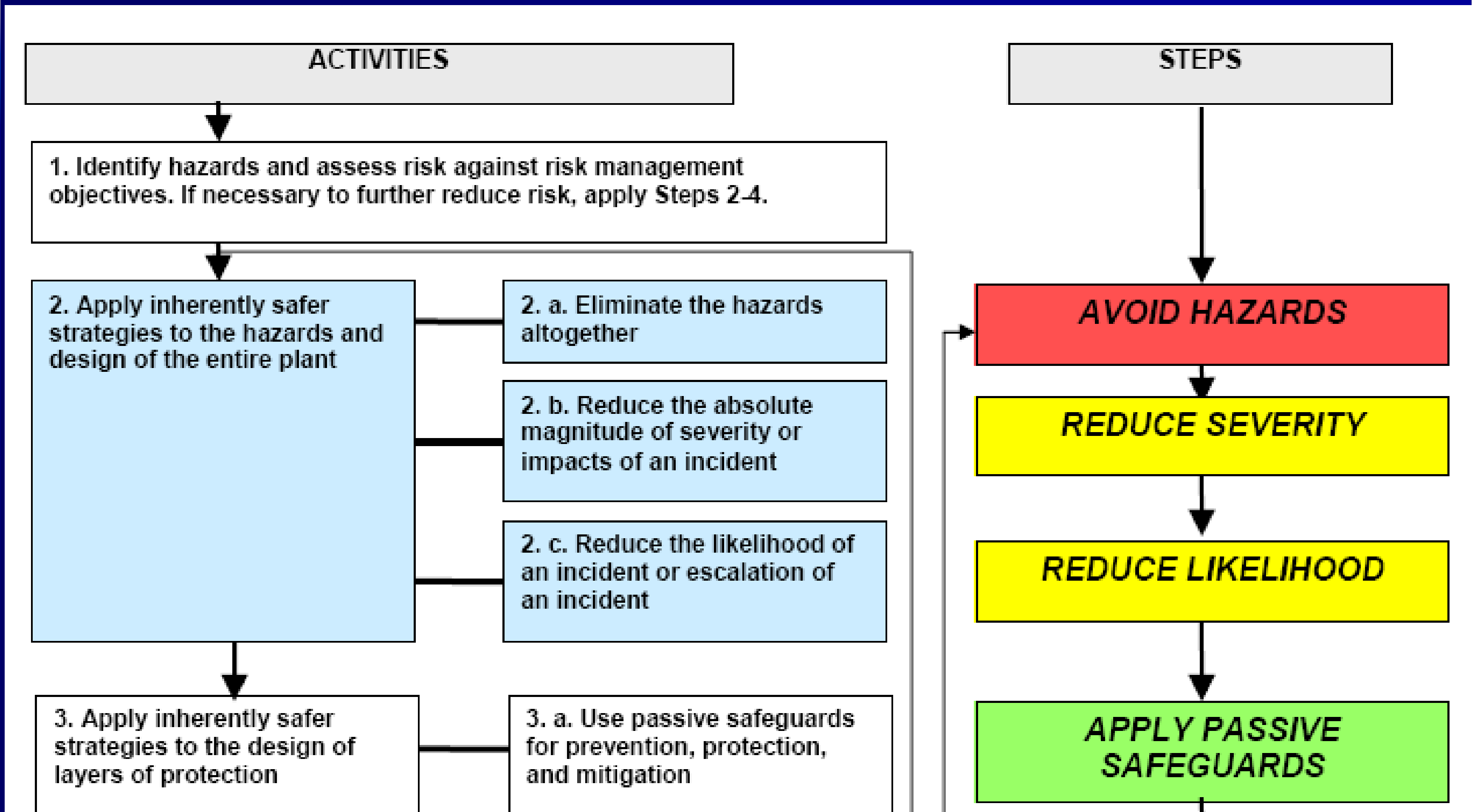
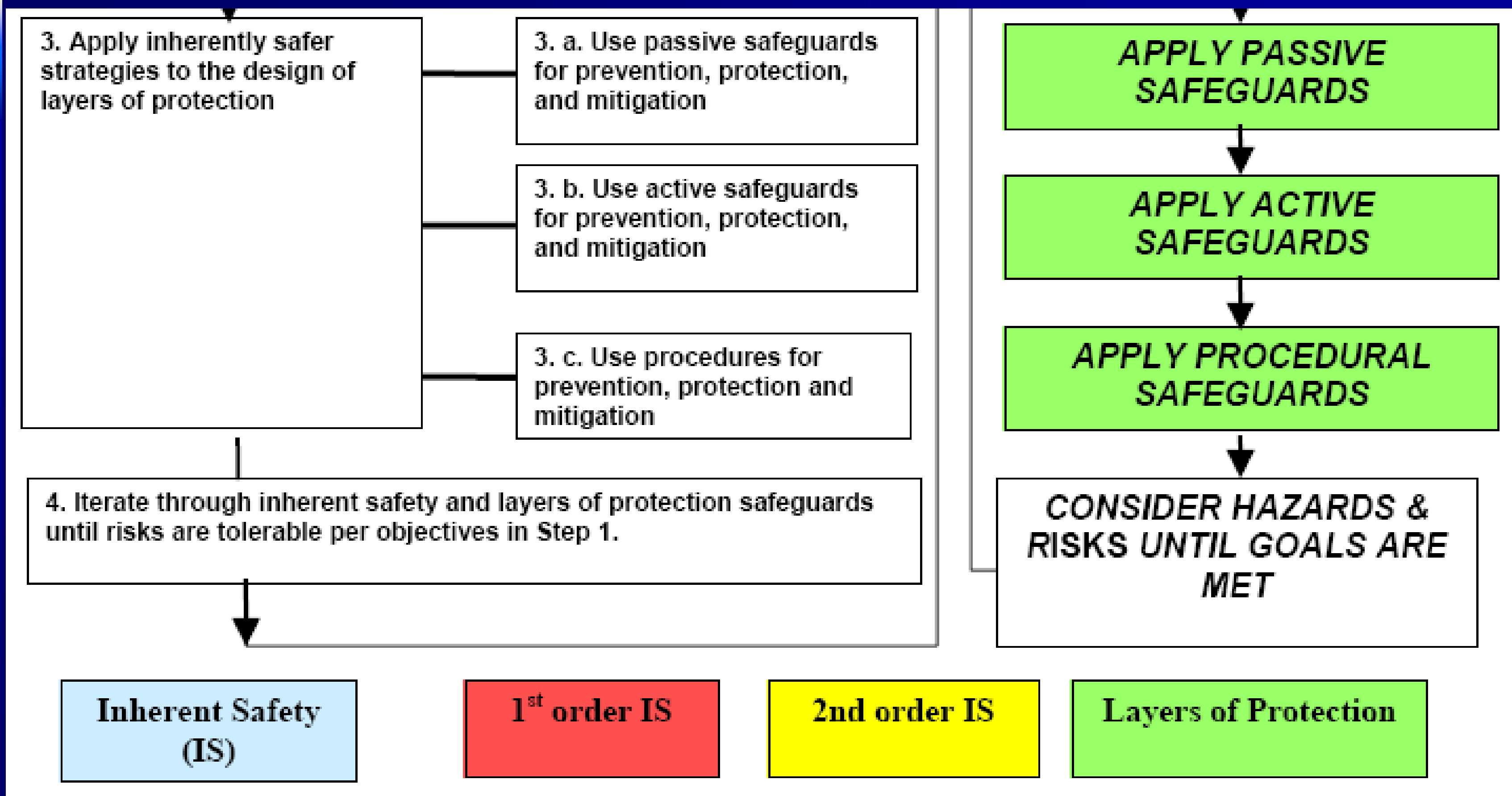


Figure 1 - Continued



Inherently Safer Technology (IST) First v. Second Order

- First order is a change resulting in the highest degree of risk reduction possible by employing the strategy
  - For example, elimination of a material from site with no need for substitution
- Second order is anything less than that and varies in level of risk reduction
  - Substitution of one material for a ‘more inherently safe’ material – still have a consequence, just reduced or different
  - Minimization, but not complete elimination

Example of Minimization

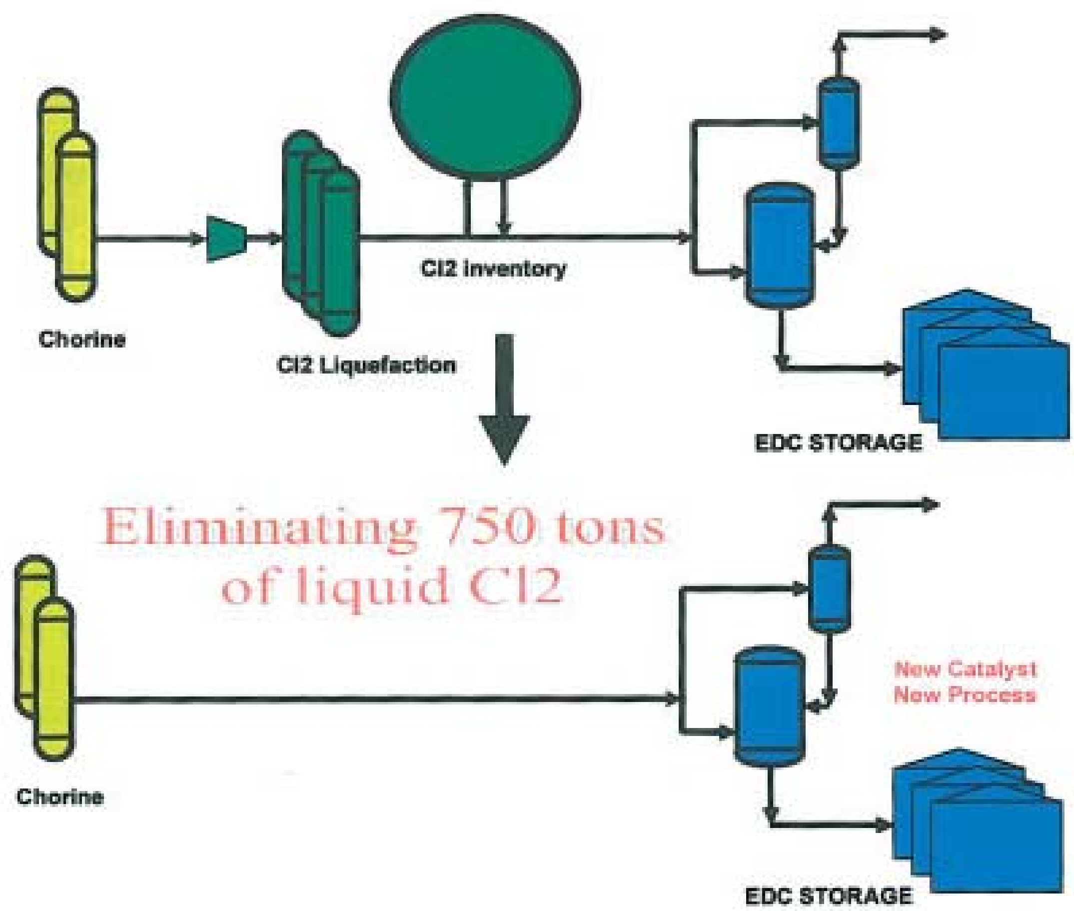


Figure 1: Original batch reaction system (Carrithers, Dowell and Hendershot)

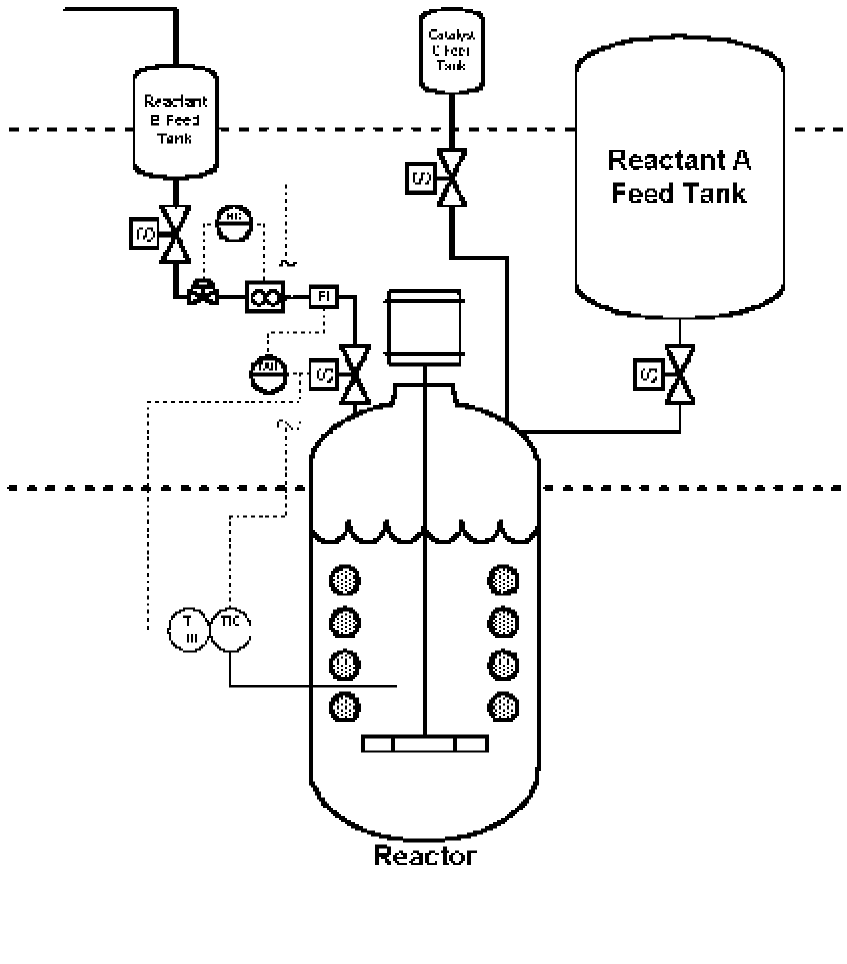
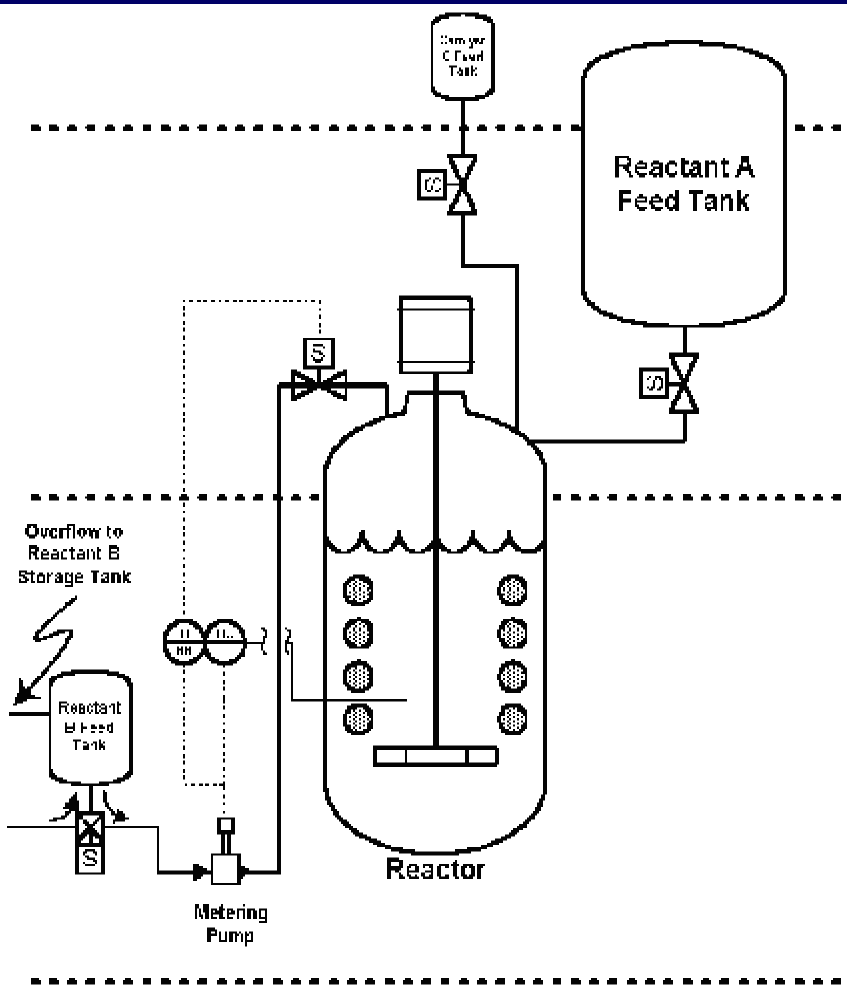


Figure 2: Modified, Inherently Safer Batch Reactor System

(Carrithers, Dowell and Hendershot)



Inherently Safer Technology (IST) – What It Is and Isn't

- It is not a 'Technology' necessarily
- It could be a reduction in materials onsite using the same technology
- It could be a procedure that is simplified in the broadest definition of IS
- If the technology is to be changed the economics often aren't favorable for changing existing plants

Chemical Security and Inherent Safety

- New appreciation of intentional acts against hazardous materials
- Public concerns increased
- Cases not previously considered credible are being expected
- Pressure for regulation and action
- Some changes are reasonable and sensible, some are unreasonable

Regulatory Proposals Related to Inherent Safety

- Strategies:
  - Consideration or implementation of inherently safer processes to entertain or mandate IST
  - Reducing consequences through changing inventories, substitution, or changing production methods and processes
  - Avoidance of hazards by rerouting of transported materials (DC Rail)
  - Employing inherently safer technologies in the manufacture, transport, and use of chemicals

Regulatory Proposals Related to Inherent Safety

- Proof of Application:
  - Proving most inherently safe 'system'
  - Proving each hazard is made inherently safe

Public Perception of Inherent Safety

- Often inherent safety is seen as 'obvious' and 'common sense' when in reality the big picture may not be that simple.
- Risk-risk tradeoffs can have unfortunate results if not properly evaluated.

Inherently Safer Technology (IST) and Security – What It Is and Isn't

- IS may be useful for reducing consequences of an intentional act but:
  - It may not address the reduction of vulnerability – consequence reduction only
  - It may be less secure – transportation
  - Other security methods may be more cost effective – and lower vulnerabilities more effectively

Public Perception of Inherent Safety

- Priorities to inherent safety may mean compromises elsewhere.
- Efforts to reduce risks often neglect the possibility that measures to reduce the "target risk" may introduce or enhance "countervailing risks."

Holistic Approach

- We need to consider risk management interventions, not a single risk reduction strategy alone.

IST Timing and Costs

- IST best implemented at research/ design stages – lower costs may be possible
- IST reviews normally incorporated into PHA for existing facilities
- Costs of implementing changes vary widely with the issue and possible solutions identified

Conflicts and Tradeoffs

- Inherently safer is in the context of one or more of the multiple hazards
  - There may be conflicts
  - Example - CFC refrigerants
    - low acute toxicity, not flammable
    - potential for environmental damage, long term health impacts

    Are they inherently safer than alternatives such as propane (flammable) or ammonia (flammable and toxic)

Multiple Impacts

- Different populations may perceive the inherent safety of different technology options differently
  - Example - chlorine handling - 1 ton cylinders vs. a 90 ton rail car
  - What if you are a neighbor two miles away?
    - Most likely would consider the ton cylinder inherently safer
  - What if you are an operator who has to connect and disconnect cylinders 90 times instead of a rail car once?
    - Most likely would consider the rail car inherently safer

Inherent Safety Challenges

- Focus on IS as a 'panacea' is not effective and regulating it is problematic:
  - IS may conflict with other goals – even safety
  - Risk:Risk tradeoffs may be worse
  - Inherent Safety is not always an objective decision
  - Neither industry nor government are clear on how to regulate it fairly and adequately
  - Regulation may limit application of IS
    - need to study every suggestion and documentation
    - snapshot studies vs. 'way of doing business'

Limitations of Inherently Safer Systems

- For example, changing to a “just-in-time” inventory system could increase shipments to a facility, thereby increasing the risk associated with transportation.
- In certain cases, it may not be feasible to create an inherently safer system especially at a macro level.

Broad vs Narrow Definition of Inherent Safety

- Inherent Safety can apply at different levels:
- Macro viewpoint –
  - A more strategic viewpoint for community
  - Consideration of overall societal risk
  - What is the best option for the community/society/nation?

Broad vs Narrow Definition of Inherent Safety

- Micro viewpoint –
  - A more tactical, company or site viewpoint
  - Inherent safety decisions focused on reducing risks to a particular site
  - Not necessarily consistent or beneficial to society as a whole.

Means to Institutionalize IS

- Policy and procedure
  - Management commitment, accountability
  - Policy, procedures encouraging IS
  - Principles, goals and incentives
  - Auditing protocols
- Practical tools to facilitate IS
  - Checklists
  - Analytical methods
    - Independent/dedicated
    - Integrated during routine activities
  - Indices

Possible IST Review Team Members

- Facilitator/Scribe
- Process Engineering or Technologist
- Design Engineering
- Operations
- Maintenance
- EHS
- Security

IST Review Methodology

- For each covered process:
  - Identify IST improvements already made
  - Review existing PHA recommendations for IST opportunities
  - For each IST checklist item, identify:
    - Current status (including N/A, IST implemented, or existing PHA recommendation)
    - Any recommendations/followup
    - Responsible person for followup
    - Resolution including completion or rationale for rejection

Life Cycle Timing for IS Analysis for New Processes

Project Stage
■ Chemistry forming (synthesis) phase
■ Facilities design scoping and development
■ Basic design phase

Life Cycle Timing for IS Analysis for Existing Processes

Project Stage
■ Modification
■ Operating
■ Decommissioning

Recommendations

- IS should be promoted as a way of doing business
- Develop methods to measure various inherent safety options – risk matrix
- Develop guidance on how to conduct an IS review internally
- If conducting an IS study for regulatory purposes be prepared to explain:
  - basis of your decisions on 'how safe is safe enough'
  - technical basis of IS method used

Inherently Safer Design Analysis Approaches

- Multiple ways inherent safety can be analyzed
- Intent is to formalize consideration of inherent safety rather than to include it by circumstance
- Including inherent safety in either a direct or indirect way, potential benefits are fully realized and considerations are documented

- Three methods can be employed:
  - Checklist Process Hazard Analysis (PHA)
  - Independent Process Hazard Analysis (PHA)
  - Integral to Process Hazard Analysis (PHA)

Risk Ranking Scheme

- In all cases it is recommended to use a risk ranking scheme which defines likelihood and consequences
- Inherent safety should be considered in light of risks as with other risk management strategies.
- A basis for decisions is needed.

AcuTech
Process Risk Management

Risk Ranking Scheme

- Table 1: Risk Matrix (R)

Likelihood	Very High (4)	Medium 2	High 3	Very High 4	Very High 4
	High (3)	Low 2	Medium 3	High 4	Very High 4
	Medium (2)	Low 2	Medium 3	Medium 3	High 4
	Low (1)	Low 1	Low 2	Low 3	Medium 3
		Low (1)	Medium (2)	High (3)	Very High (4)
		Severity			

Risk Ranking Scheme (continued)

Table 2: Severity (S)

Category	Low (1)	Medium (2)	Moderate (3)	High (4)
Health & safety impacts	Minor injury or health effect	Moderate injury or health effect	Major injury or health effect; offsite public impacts	Fatality offsite, multiple onsite injuries or fatalities,
Asset damage (replacement cost)	$	$$	$$$	$$$$
Business interruption (days unavailable or $)	$	$$	$$$	$$$$
Environmental impact (remediation damages)	$	$$	$$$	$$$$

Risk Ranking Scheme (continued)

Table 3: Likelihood (L)

Likelihood	Short descriptor	Description
1	Low	Not expected to occur in life of facility
2	Medium	Possible to occur in life of facility
3	High	Possible to occur in range of 1 year to 10 years
4	Very High	Possible to occur at least once a year

Inherent Safety Analysis Method Synopsis

- Method 1 – a checklist is used that contains a number of practical inherent safety considerations organized around the four strategies of minimization, substitution, moderation, and simplification
  – Direct & asks pointed questions that have proven to be valuable in reducing hazards at past locations
  – May be limiting; other ideas may surface if the team was asked to more creatively determine applications for the inherent safety strategies given a safety objective

Inherent Safety Analysis Method Synopsis

- Method 2 – team is asked to avoid a particular hazard at a part of the process
  - Team reviews a problem and determines which of the inherently safer strategies may apply and brainstorms possible ways the hazard can be reduced or eliminated.

Inherent Safety Analysis Method Synopsis

- Method 3 – integrate ISD into every PHA study (What if?, HAZOP, FMEA or other similar methodology)
  - The concept is both to include questions (for What if?) or guidewords (for HAZOP) to introduce ISD to the discussion, and then to use the four strategies (minimization, substitution, moderation, and simplification) as possible means to mitigate each hazard identified in addition to the other layers of protection strategies that may be used

Checklist Process Hazard Analysis (PHA)

Figure 1
Inherent Safety Analysis – Checklist Process Hazard Analysis (PHA)

Location:						**Risk Ranking**			**Unit**: Hydrofluoric Acid Alkylation unit	**Analysis Date:** April 1, 2008
PFD No.: 1234-5678										
Node:: Isobutane Storage										
Design Conditions/Parameters: Storage of isobutene in five bullets and two process vessels near the unit										
	QUESTION	**POTENTIAL OPPORTUNITIES**	**FEASIBILITY**	**CONSEQUENCES**	**EXISTING SAFEGUARDS**	**S**	**L**	**R**	**RECOMMENDATIONS**	**COMMENTS/STATUS**
1	Reduce hazardous raw materials inventory	Lower storage tank volume or eliminate some storage if possible.	Lowering tank volumes is already done. There may be one tank that could be eliminated.	Potential release from storage and exposure to south plant from unconfined vapor cloud explosion.	1. Administrative controls limit fill level of the five tanks.	4	1	3	1. Eliminate one of five flammable storage bullets to reduce potential releases from storage.	In review.
2	Reducing in-process storage and inventory	Interim storage adds to inventory and could be eliminated.	Will require engineering analysis to evaluate.	Potential leak, fire and explosion.	1. High level alarms 2. Flammable gas detectors	4	1	3	2. Consider eliminating interim storage and providing a continuous flow operation	In review
3	Reducing finished product inventory	Not applicable (NA)								
4	Reduce hazardous material by using alternate equipment		No alternatives available or feasible							

Independent Process Hazard Analysis (PHA)

Figure 2
Inherent Safety Analysis - Independent Process Hazard Analysis (PHA)

Node: 1. Feed system to reactor

Objective: 1. Minimize potential for runaway reaction in the feed to the reactor

CAUSES	CONSEQUENCES	EXISTING SAFEGUARDS	S	L	R	OPPORTUNITIES	FEASIBILITY	RECOMMENDATIONS	COMMENT//STATUS
1. High water content in feed tank due to settlement or water carryover from upstream process	1. Excess water in the reactor may cause shorter run life due to catalyst fouling; this has a possible safety hazard in more startups and shutdowns over the life of the process. Worst credible case excessive water may cause a runaway reaction.	1. Control of unit operation to meet feed and operator monitoring of process conditions.	4	4	4	Evaluate way to positively eliminate water from entering the reactor rather than controls.	It may be feasible to switch to a 'clean' tank without the potential for water with minor piping changes.	1. Change from feeding from Tank 1 to only Tank 3 since Tank 1 has high water settlement potential. Tank 1 has water in upstream units that cannot be completely avoided whereas Tank 3 is clean feedstock.	
2. Water into the feed from wrong valve opened in one of the water wash cross connections	1. Potential for operator error to leave water online or valve not fully closed, or failure of the valve allowing leak of water into the feed line.	1. Proper procedures for water washing	4	2	4	Evaluate ways to eliminate water contamination risk from human error	Operating procedures can be improved.	2. Improve operating procedures for water washing to ensure operators check the valve closure and water flow following a water wash.	
		2. Operator training 3. Temperature					There is an excess number of cross connections so	3. Reduce the number of water cross connections.	

Integral to Process Hazard Analysis (PHA)

Figure 3
Inherent Safety Analysis – Integral to Process Hazard Analysis (PHA)

Node: 1. Feed system to reactor

Intent: 1. Feed to the process

Guideword: As Well As **Parameter: Flow** **Deviation: Contamination**

CAUSES	CONSEQUENCES	EXISTING SAFEGUARDS	S	L	R	OPPORTUNITIES	FEASIBILITY	RECOMMENDATIONS	COMMENT/STATUS
1. Settlement or water carryover from upstream process	1. Excess water in the feed and then reactor which may cause shorter run life due to catalyst fouling; this has a possible safety hazard in more startups and shutdowns over the life of the process. Worst credible case excessive water may cause a runaway reaction.	1. Control of unit operation to meet feed and operator monitoring of process conditions.	4	4	4	Evaluate way to positively eliminate water from entering the reactor rather than controls	It may be feasible to switch to a 'clean' tank without the potential for water with minor piping changes.	1. Change from feeding from Tank 1 to only Tank 3 since Tank 1 has high water settlement potential. Tank 1 has water in upstream units that cannot be completely avoided whereas Tank 3 is clean feedstock.	
2. Potential for operator error to leave water online or valve not fully closed, or failure of	1.. Excess water in the reactor may cause shorter run life due to catalyst fouling; this has a possible	1. Proper procedures for water washing	4	2	4	Evaluate ways to eliminate water contamination risk from human error	Operating procedures can be improved.	2. Improve operating procedures for water washing to ensure operators check the valve closure and water flow following a water wash.	