Chemical
SAFETY AND SECURITY TRAINING

Inherently Safer Design

SAND No. 2011-0721P

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for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

Sandia National Laboratories

Key acronyms

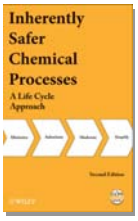
IS = *inherent safety*

ISD = *inherently safer design*

IST = *inherently safer technology*

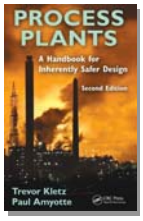
Inherent safety resources

CCPS 2008c. Center for Chemical Process Safety, ***Inherently Safer Chemical Processes: A Life Cycle Approach, 2nd Edition***. NY: American Institute of Chemical Engineers.



Inherent safety resources

T.A. Kletz and P. Amyotte 2010. ***Process Plants: A Handbook for Inherently Safer Design, 2nd Edition***. Boca Raton, Florida: CRC Press.



Inherent safety resources

CCPS 2008a. Center for Chemical Process Safety, *Guidelines for Hazard Evaluation Procedures, Third Edition*, NY: American Institute of Chemical Engineers.

- Inherent safety reviews
- Appendix A4: Inherently Safer Process Checklist

Inherent safety resources

DHS 2010. "Final Report: Definition for Inherently Safer Technology in Production, Transportation, Storage, and Use." Prepared by CCPS for U.S. Department of Homeland Security. July 2010.

On course CD-ROM

Inherently Safer Design

1. What is "inherent safety"?
2. Why is it important?
3. What are the basic inherent safety strategies?
4. What are some other, related strategies?
5. How is it implemented in a facility's life cycle?
6. What are some limitations of inherent safety?
7. Class discussion and exercise

Inherently Safer Design

1. What is "inherent safety"?

Formal definition

Inherently Safer Technology (IST), also known as ***Inherently Safer Design*** (ISD), **permanently eliminates or reduces hazards to avoid or reduce the consequences of incidents.**

DHS 2010

Formal definition (continued)

- IST is a philosophy, applied to the design and operation life cycle, including manufacture, transport, storage, use, and disposal.
- IST is an iterative process that considers such options, including eliminating a hazard, reducing a hazard, substituting a less hazardous material, using less hazardous process conditions, and designing a process to reduce the potential for, or consequences of, human error, equipment failure, or intentional harm.

ISTs are *relative*

- A technology can only be described as *inherently safer* when compared to a different technology, including a description of the hazard or set of hazards being considered, their location, and the potentially affected population.
- A technology may be inherently safer than another with respect to some hazards but inherently less safe with respect to others, and may not be safe enough to meet societal expectations.

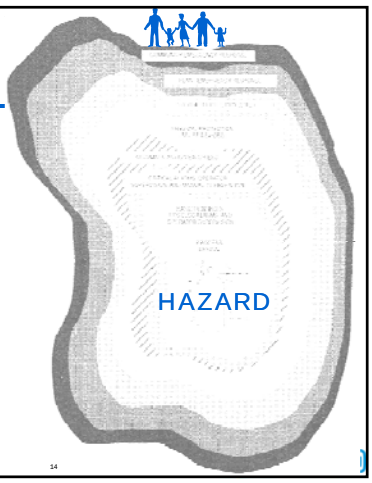
ISTs are based on an *informed decision process*

- Because an option may be inherently safer with regard to some hazards and inherently less safe with regard to others, decisions about the optimum strategy for managing risks from all hazards are required.
- The decision process must consider the entire life cycle, the full spectrum of hazards and risks, and the potential for transfer of risk from one impacted population to another.
- Technical and economic feasibility of options must also be considered.

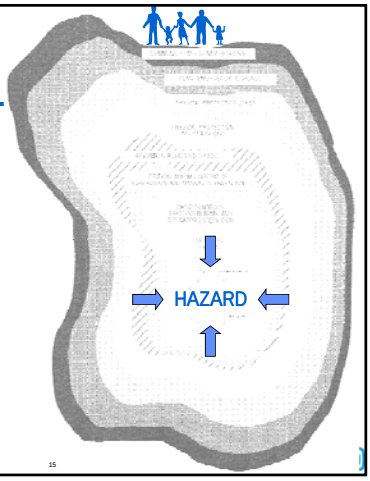
"The essence
of the inherently safer approach
to plant design
is the **avoidance of hazards**
rather than their control
by added-on protective equipment."

T. A. Kletz, *Plant Design for Safety: A User-Friendly Approach* (NY: Hemisphere, 1991)

Hazard reduction



Hazard reduction



Inherently cleaner, safer plants

Environ-mental Restoration	Waste Management	Pollution Prevention	Inherently Cleaner Processes

AFTERMATH >>>>> RELEASE >>>>> HAZARD

Accident Recovery	*Mitigation*	*Prevention*	*Inherently Safer Processes*

Inherently Safer Design

1. What is "inherent safety"?
2. **Why is "inherent safety" important?**

Inherently safer designs

permanently and inseparably

reduce or eliminate process hazards

that must be contained and controlled to avoid loss events.

Importance of inherent safety

- **Seminal paper by Trevor Kletz:**

"What you don't have, can't leak"

(*Chemistry and Industry*, 6 May 1978, pp 287-292)

Importance of inherent safety

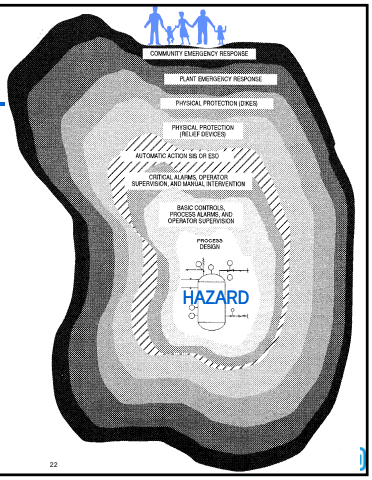
- **Security corrollary:**

What you don't have can't be stolen, ignited or intentionally released.

Importance of inherent safety

Those hazards that are <u>not</u> eliminated or reduced to insignificance must be managed throughout the lifetime of the facility, to avoid process incidents that can result in loss and harm.

"Layers of Protection" are needed to protect against hazards that are <u>not</u> eliminated



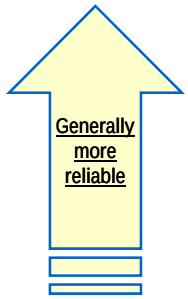
Possible inherent safety <u>benefits</u>

- **Reduce** the need for engineered controls and safety systems (including initial and ongoing ITM costs)
- **Reduce** labor costs and potential liabilities associated with ongoing regulatory compliance
- **Eliminate** the need for personal protective equipment associated with particular hazards
- **Reduce** emergency preparedness and response requirements
- **Improve** neighborhood / community relations

RECALL: Part of formal IST definition

- Overall safe design and operation options cover a spectrum from **inherent** through **passive**, **active** and **procedural** risk management strategies.
- There is no clear boundary between IST and other strategies.

Four types of process safety strategies



- **Inherent** - Hazard reduction
- **Passive** - Process or equipment design features that reduce risk without active functioning of any device
- **Active** - Engineering controls
- **Procedural** - Administrative controls

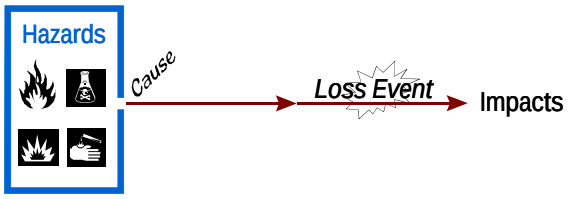
DISCUSSION

What are a couple of examples of each strategy?

- **Inherent** - Hazard reduction
- **Passive** - Process or equipment design features that reduce risk without active functioning of any device
- **Active** - Engineering controls
- **Procedural** - Administrative controls

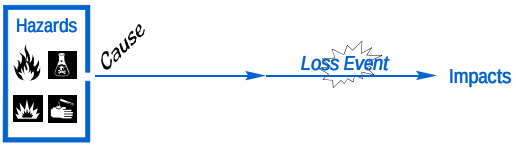
One more vantage point

Reducing the underlying hazards...



One more vantage point

… can reduce potential loss event impacts.



Inherently Safer Design

1. What is "inherent safety"?
2. Why is it important?
3. **What are the basic inherent safety strategies?**

Basic inherent safety strategies

CCPS 2008:	*Kletz and Amyotte 2010:*
Minimize	Intensify
Substitute	Substitute
Moderate	Attenuate
Simplify	Limit Effects
	Simplify

Basic inherent safety strategies

CCPS 2008:	*Kletz and Amyotte 2010:*
Minimize ⟷	Intensify
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	Simplify

Basic inherent safety strategies

Focus in this course:

Minimize
Substitute
Attenuate

Basic inherent safety strategies

Focus in this course:

Minimize

Substitute

Attenuate

RECALL: Part of formal IST definition

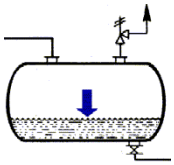
- IST is an iterative process that considers such options, including **eliminating a hazard, reducing a hazard**, substituting a less hazardous material, using less hazardous process conditions, and designing a process to reduce the potential for, or consequences of, human error, equipment failure, or intentional harm.

Minimize

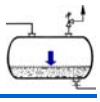
To *minimize* is to reduce the amount of potential energy present

(i.e., get the system closer to a zero energy state),

thus reducing the potential impacts if containment or control of the hazard is lost.



Minimize



Some strategies for making a process inherently safer by *minimization*:

- **Inventory reduction; e.g.,**
  - **less material stored**
  - **fewer tanks; just-in-time delivery**
  - **less vapor volume**
  - **generate on demand** (chlorine, MIC, ammonia, hydrogen...)
  - **receive by pipeline instead of by truck or rail**
- **Process intensification**
- **Process operation closer to ambient conditions**

Minimize

Some strategies for making a process inherently safer by *minimization*:

- **Inventory reduction; e.g.,**
  - **less material stored ⇐ *requires administrative control***
  - **fewer tanks; just-in-time delivery**
  - **less vapor volume**
  - **generate on demand** (chlorine, MIC, ammonia, hydrogen...)
  - **receive by pipeline instead of by truck or rail**
- **Process intensification**
- **Process operation closer to ambient conditions**

Minimize

Ultimate case:

- **Elimination of the hazard; e.g.,**
  - **Eliminating use of a particular hazardous material**
  - **Operating the system at a zero energy state with respect to a particular hazard**
  - **Shutting down the process**
  - **Using a toll manufacturer (risk *transfer*)**

DISCUSSION

- **An inherent safety review recommends eliminating intermediate storage of a hazardous raw material:**

Raw Material Manufacture → Raw Material Usage

- **What are the inherent safety benefits?**
  -
  -
- **What are the possible drawbacks?**
  -
  -

Basic inherent safety strategies

Focus in this course:

Minimize

Substitute

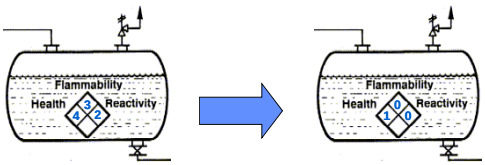
Attenuate

RECALL: Part of formal IST definition

- IST is an iterative process that considers such options, including eliminating a hazard, reducing a hazard, **substituting a less hazardous material,** using less hazardous process conditions, and designing a process to reduce the potential for, or consequences of, human error, equipment failure, or intentional harm.

Substitute

To *substitute* is to replace with a less hazardous material or condition.



Substitute

Some strategies for making a process inherently safer by *substitution*:

- **Commercially available alternatives**
- **Alternative raw material or intermediate that can be transported and stored more safely**
- **Alternative chemistry**
  - Propylene oxidation process instead of Reppe process for manufacture of acrylic esters
  - Biosynthesis routes

Substitute

Some chlorine alternatives:

- **Sodium hypochlorite**
- **Calcium hypochlorite**
- **Hydrogen peroxide**
- **Chlorine dioxide**
- **Bromine**
- **Mixed oxidants**

Substitute

Some chlorine alternatives:

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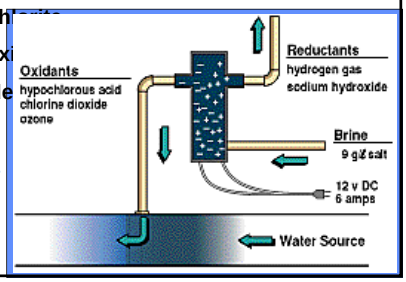


Substitute

Oleum alternative:

- **Sulfur burning to generate SO_3 on demand**

Substitute

Solvent substitutes:

- **Water-based paints, adhesives**
- **Aqueous cleaning systems**
- **Less volatile solvents; higher flash point**
- **Dibasic esters for paint stripping**

Web resources are available

- **E.g., "Substitutes in Non-Aerosol Solvent Cleaning,"** http://www.epa.gov/ozone/snap/solvents/solvents.pdf

Basic inherent safety strategies

Focus in this course:

Minimize

Substitute

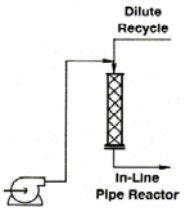
Attenuate

RECALL: Part of formal IST definition

- IST is an iterative process that considers such options, including eliminating a hazard, reducing a hazard, substituting a less hazardous material, **using less hazardous process conditions,** and designing a process to reduce the potential for, or consequences of, human error, equipment failure, or intentional harm.

Attenuate

To *attenuate* (or *moderate*) is to handle a material under less hazardous process conditions.



Attenuate

To *attenuate* (or *moderate*) is to handle a material under less hazardous process conditions.

Note: Available energy may be the same, but potential loss event impacts can be reduced

Attenuate

Some strategies for making a process inherently safer by *attenuation*:

- **Dilution**
  - **E.g., using in aqueous instead of anhydrous form**
  - **Using in solution such that the solute would boil off before a runaway reaction temperature was achieved**
  - **Lower concentration of benzoyl peroxide in paste**
  - **Mixing coal dust with rock dust**
- **Refrigeration**
  - **E.g. storing anhydrous ammonia as a refrigerated liquid instead of as a liquefied gas**

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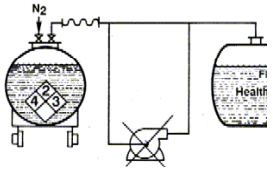
Basic inherent safety strategies

CCPS 2008:	*Kletz and Amyotte 2010:*
Minimize	Intensify
Substitute	Substitute
Moderate	Attenuate
Simplify	Limit Effects
	Simplify

Simplify

To *simplify* is to eliminate unnecessary complexity.



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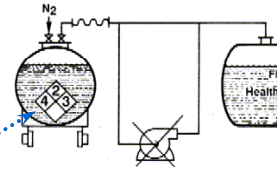
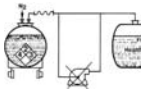


(Not "first-order" inherent safety, since the underlying hazard is still there.)

Simplify

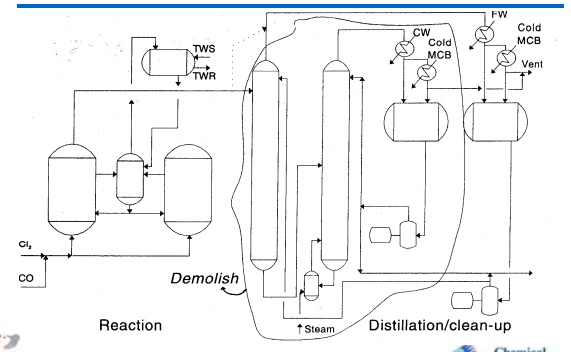


Some *simplification* strategies:

- **Use simpler equipment arrangement**
  - **E.g., gravity flow**
  - **Natural convection**
- **Eliminate interconnections to reduce the likelihood of inadvertent mixing**
- **Minimize number of flanges, connections, and other potential leak locations**

Simplification of Dow Phosgene Unit for MDI Production

R. Gowland, "Applying Inherently Safer Concepts to a Phosgene Plant Acquisition," *Process Safety Progress 15*(1), 57



Limit Effects

The greatest opportunity to limit effects is generally by increasing the *distance* between the potential loss event location and the people, property and environment that could be affected.

CGA, *Handbook of Compressed Gases*

Inherently Safer Design

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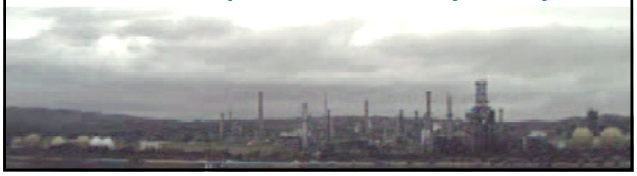
5. **How is it implemented in a facility's life cycle?**



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Two basic IS activities

1. **Design and build inherent safety into a process**
2. **Continually look for ways to reduce or eliminate hazards throughout the process life cycle**

Two basic IS activities - By Whom?

1. **Design and build inherent safety into a process**
   [INHERENT SAFETY REVIEWS / R&D / ENGINEERING]
2. **Continually look for ways to reduce or eliminate hazards throughout the process life cycle**
   [INHERENT SAFETY REVIEWS / PHAs / ENGINEERING]

Inherent safety reviews

Most effective life cycle phases to review a process process for opportunities to make it inherently safer (CCPS 2008a):

- **R&D**
- **Conceptual design**
- **Detailed engineering**
- **Routine operation**

(Members of review team will vary depending on life cycle phase)

Inherent safety reviews

Typical inherent safety review steps (CCPS 2008a):

1. **Collect and review background information**
2. **Identify / define / document the major hazards**
3. **Review the process flow schematic**
   - **Look at each process step and hazardous material**
   - **Identify creative ways to improve the process by applying inherently safer principles to reduce or eliminate hazards**
4. **Document the review and follow-up actions**

Inherent safety reviews

Good resource for IS reviews (CCPS 2008a, Appx. A4):

"An Inherently Safer Process Checklist"

1 Intensification / Minimization

1.1 Do the following strategies reduce inventories of hazardous raw materials, intermediates, and/or finished products?
- Improved production scheduling
- Just-in-time deliveries
- Direct coupling of process elements
- Onsite generation and consumption

1.2 Do the following actions minimize in-process inventory?
- Eliminating or reducing the size of in-process storage vessels
- Designing processing equipment handling hazardous materials for the smallest feasible inventory
- Locating process equipment to minimize the length of hazardous material piping runs
- Reducing piping diameters

1.3 etc.

Inherently Safer Design

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5. How is it implemented in a facility's life cycle?
6. **What are some limitations of inherent safety?**

CAUTION

Inherently Safer* does not necessarily mean *lower risk!

- Process change may introduce new hazards
  - E.g., hydrogen gas generated by hydrolysis
- Loss event likelihood may be affected
  - E.g., Supplying from many small cylinders instead of one large cylinder increases frequency of connecting and disconnecting cylinders
- Loss event severity can also be affected
  - E.g., total containment increases burst pressure

DISCUSSION

Situation: You need to travel from a city at one part of the country to the most distant large city.

Your options: Travel by land or travel by commercial airline.

- **Which option is *inherently safer* ?**
- **Which option has *lower risk* ?**

Airline travel

HAZARDS:

- **Potential energy** (34,000 ft altitude; heavy objects in overhead bins)
- **Kinetic energy** (600 mph; other planes; rotating turbines/propellers)
- **Chemical energy** (fuel in tanks; hazmats in cargo; fire potential)
- **Temperature** (cold air outside; hot coffee inside)
- **Pressure** (low pressure outside)
- **Reduced oxygen**
- **Increased radiation**
- **Other people** (security threats; drunken or angry passengers)

Inherently Safer Design

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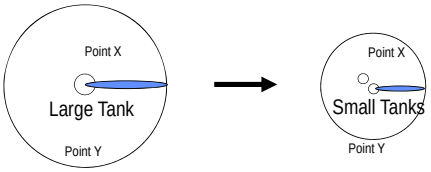
7. **Class discussion and exercise**

DISCUSSION: Volatile toxic liquid storage

Situation: One stakeholder wanted one large storage tank, another stakeholder wanted two smaller storage tanks.

Second stakeholder's rationale: Worst-case impact is half as serious.



EXERCISE

1 **Select a familiar type of simple chemical process from your industry**

2 **Identify at least three specific ideas for making the process inherently safer**

3 **Discuss whether any of the approaches might actually increase safety or security risk**

WRAP-UP DISCUSSION

- **What are some major challenges to implementing inherent safety principles?**
- **How might these be overcome?**

WRAP-UP DISCUSSION

- **Do inherent safety principles also apply to *facility security*?**