



**Chemical**  
SAFETY AND SECURITY TRAINING

**Inherently Safer Design**  
Bangkok, Thailand  
1 March 2011

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**Key acronyms**

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**IS** = *inherent safety*

**ISD** = *inherently safer design*

**IST** = *inherently safer technology*

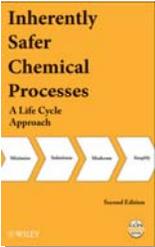




**Inherent safety resources**

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

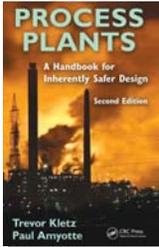





**Inherent safety resources**

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

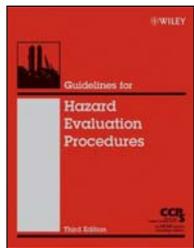






## Inherent safety resources

**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.

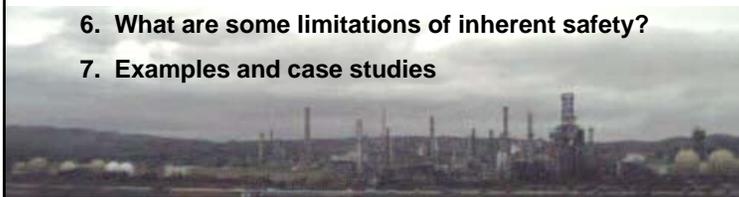


On course CD-ROM



## 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. Examples and case studies



## Inherently Safer Design

1. What is “inherent safety”?





## Formal definition

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***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)

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- 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*

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- 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*

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- 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.



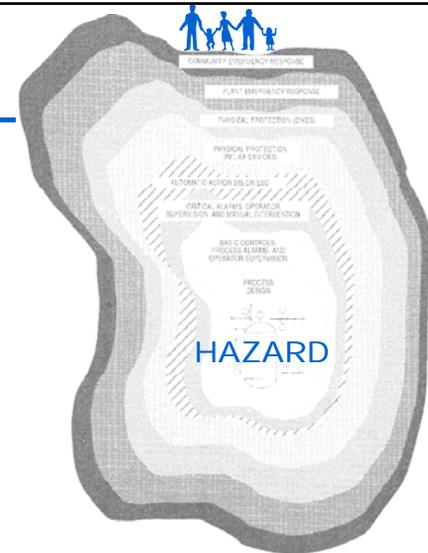


“The essence  
of the inherently safer approach  
to plant design  
is the **avoidance of hazards**  
rather than their control  
by added-on protective equipment.”

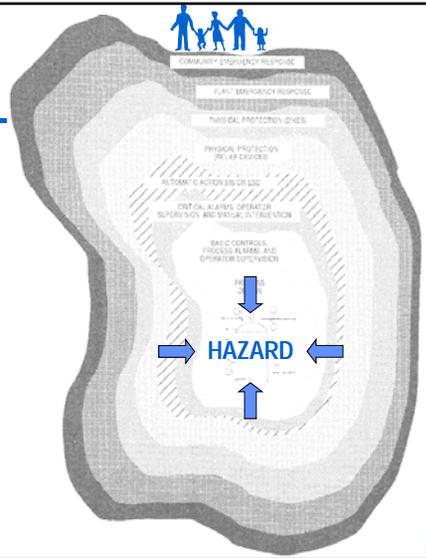
T. A. Kletz, *Plant Design for Safety: A User-Friendly Approach* (NY: Hemisphere, 1991)



## Hazard Reduction



## Hazard Reduction



## Inherently 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 corollary:

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



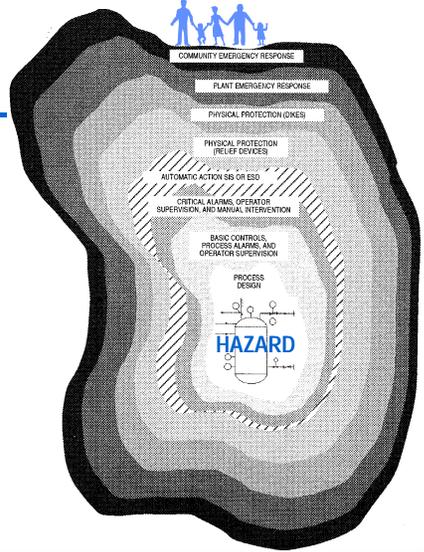
### Importance of inherent safety

Those hazards that are not 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 not eliminated



### Possible inherent safety benefits

- **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

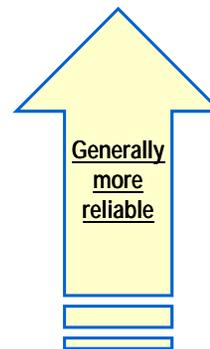


### RECALL: Part of formal IST definition

- 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

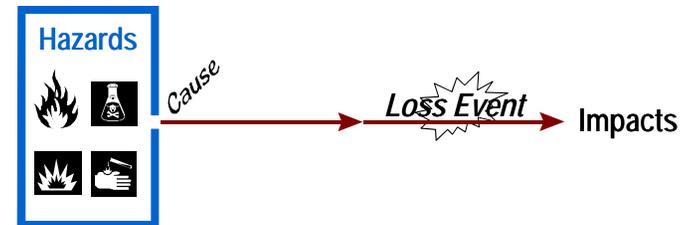
*What are some examples of each strategy?*

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



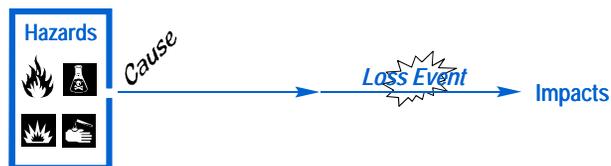
## One more vantage point

*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

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*CCPS 2008:*

Minimize  
Substitute  
Moderate  
Simplify

*Kletz and Amyotte 2010:*

Intensify  
Substitute  
Attenuate  
Limit Effects  
Simplify



## Basic inherent safety strategies

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*CCPS 2008:*

Minimize ↔ Intensify  
Substitute ↔ Substitute  
Moderate ↔ Attenuate  
Simplify ↗ Limit Effects  
Simplify

*Kletz and Amyotte 2010:*



## Basic inherent safety strategies

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*Focus in this course:*

Minimize  
Substitute  
Attenuate



## Basic inherent safety strategies

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*Focus in this course:*

Minimize  
Substitute  
Attenuate





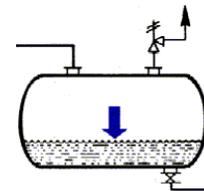
## RECALL: Part of formal IST definition

- 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.

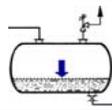


## Minimize

- 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

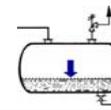


Some strategies for making a process inherently safer by **minimization**:

- **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



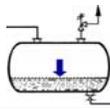
Some strategies for making a process inherently safer by **minimization**:

- **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*)



## Basic inherent safety strategies

### Focus in this course:

Minimize  
**Substitute**  
Attenuate



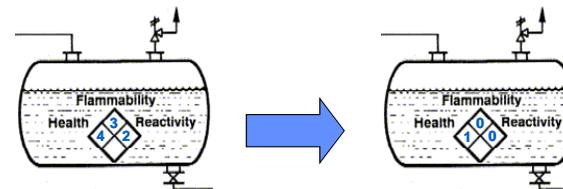
## RECALL: Part of formal IST definition

- 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.



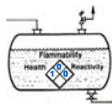
## Substitute

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





## Substitute

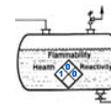


Some strategies for making a process inherently safer by **substitution**:

- Use of commercially available alternatives
  - E.g., sodium hypochlorite instead of chlorine
  - Water-based solvents instead of flammable solvents
- Use of an alternative raw material 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

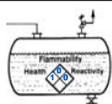


Some **chlorine alternatives** :

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

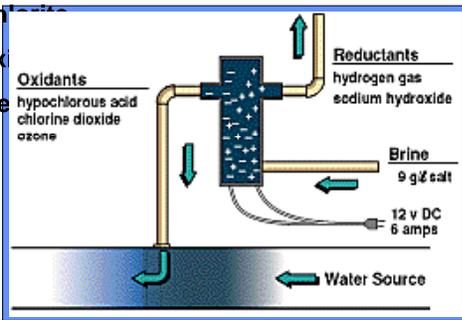


## Substitute



Some **chlorine alternatives** :

- Sodium hypochlorite
- Calcium hypochlorite
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- **Mixed oxidants**



## Basic inherent safety strategies

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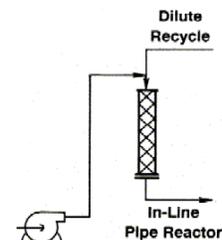
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## Attenuate

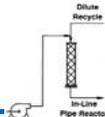
To **attenuate** (or **moderate**) is to handle a material under less hazardous process conditions.



## Attenuate

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

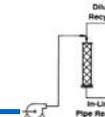
**Note:** Available energy may be the same, but potential loss event impacts can be reduced



## 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





## 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?**



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## Basic inherent safety strategies

*CCPS 2008:*

Minimize  
Substitute  
Moderate  
Simplify

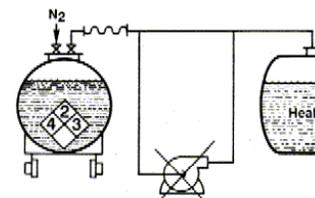
*Kletz and Amyotte 2010:*

Intensify  
Substitute  
Attenuate  
Limit Effects  
Simplify



## Simplify

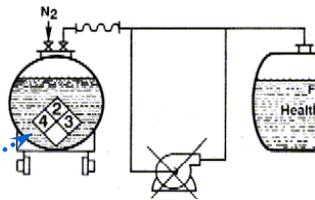
To *simplify* is to eliminate unnecessary complexity.





## Simplify

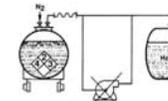
To *simplify* is to eliminate unnecessary complexity.



(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



## 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.



## Inherently Safer Design

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## Two basic IS activities

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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?

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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

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

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

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





## Inherent safety reviews

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**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



## Inherently Safer Design

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6. **What are some limitations of inherent safety?**



## CAUTION

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***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

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**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

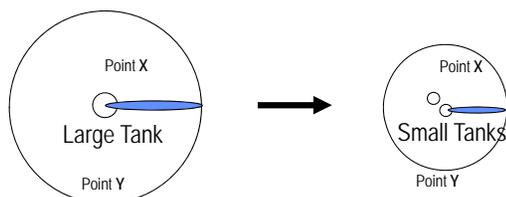
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7. **Examples and case studies**



## 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

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

