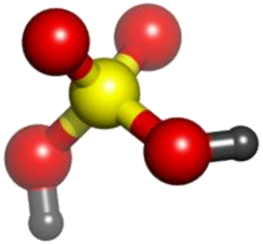


SAND2012-3406C

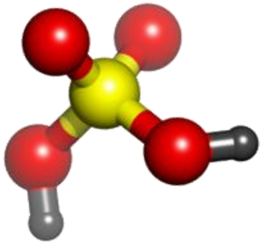
Inherently Safer Design

Bandung, Indonesia

May 2012

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories



Key definitions & acronyms

Definitions

Inherently – belonging by nature or habit

Relative – considered in relation to something else; comparative

Loss Event – point of time in an incident sequence when an irreversible physical event occurs that has the potential for loss and harmful impacts

Acronyms

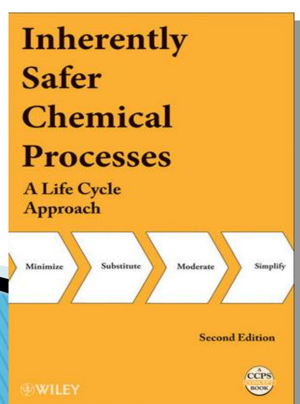
IS – inherent safety

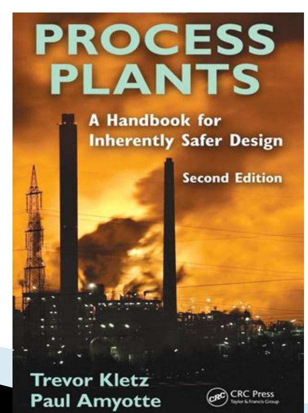
ISD – inherently safer design

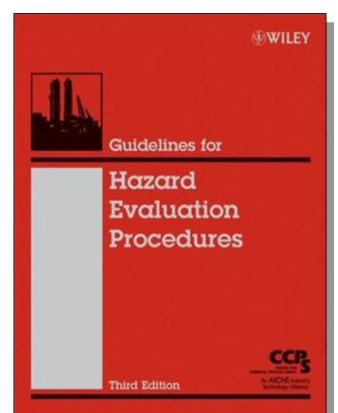
IST – inherently safer technology

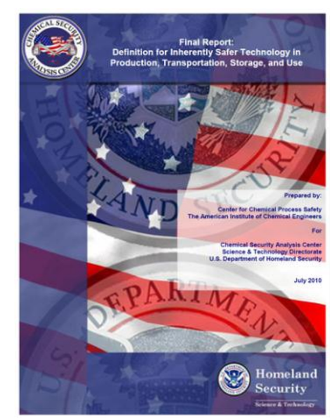
References and Additional Sources

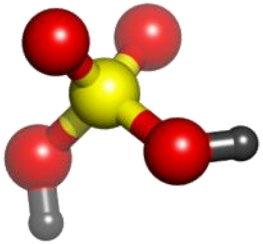
- CCPS 2008c. - Center for Chemical Process Safety, *Inherently Safer Chemical Processes: A Life Cycle Approach, 2nd Edition*.
- T.A. Kletz and P. Amyotte 2010, Process Plants: A Handbook for Inherently Safer Design, 2nd Edition.
- CCPS 2008a. - Center for Chemical Process Safety, *Guidelines for Hazard Evaluation Procedures, Third Edition*. Inherent safety reviews and Appendix A4: Inherently Safer Process Checklist
- DHS 2010 - "Final Report: Definition for Inherently Safer Technology in Production, Transportation, Storage, and Use." Prepared by CCPS for U.S. Dept. of Homeland Security (DHS). July. - On course CD-ROM





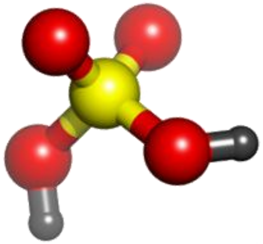






Course Objectives

1. What is “inherently safer design”?
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 "inherently safer design"?**
2.
3.
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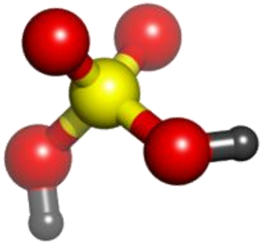

Formal definition

***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

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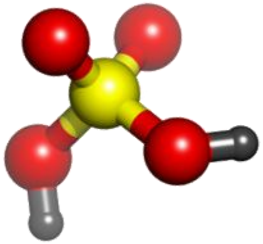
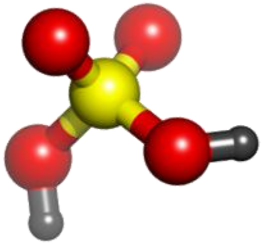


Formal definition (continued)

- **ISD** is a philosophy, applied to the design and operation life cycle, including manufacture, transport, storage, use, and disposal.

- **ISD** 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.



ISDs 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.

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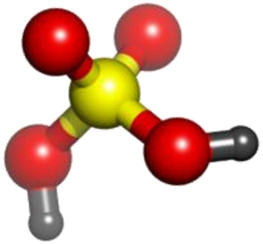
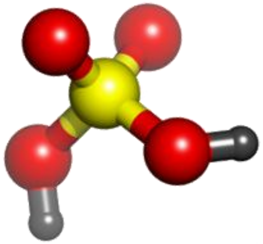


ISDs are based on an *informed decision process*

- 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.

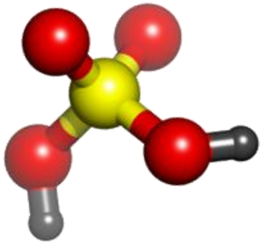


“The essence of the inherently safer approach to plant design is the **avoidance of hazards** rather than their control by added-on protective equipment.”

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

Inherently Safer Design

1. What is "inherently safer design"?
2. **Why is "inherently safer design" important?**
3.
4.
5.
6.
7.



Importance of inherent safety

Ground-breaking paper by Trevor Kletz:

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

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

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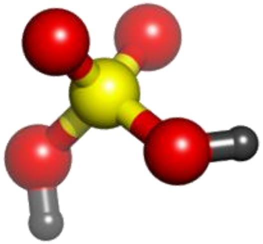

Importance of inherent safety

Security corollary:

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

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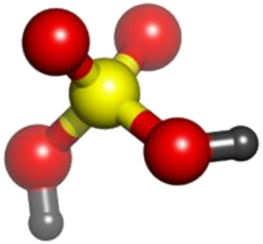
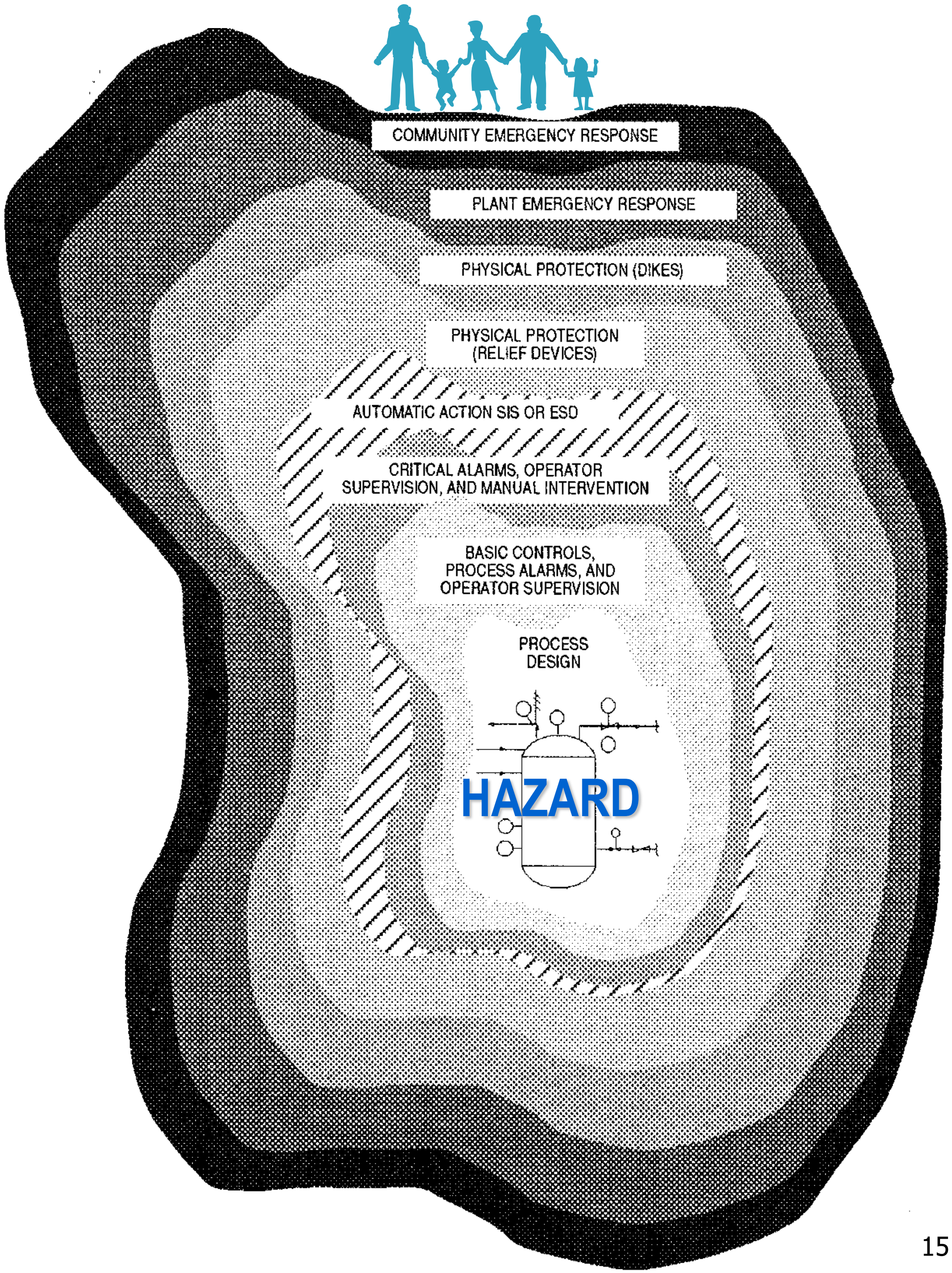


Importance of inherent safety

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



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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

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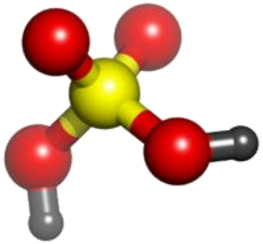
Part of formal ISD definition

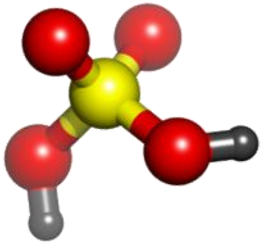
- Overall safe design and operation options cover a spectrum from inherent through passive, active and procedural risk management strategies.
- There is no clear boundary between ISD and other strategies.



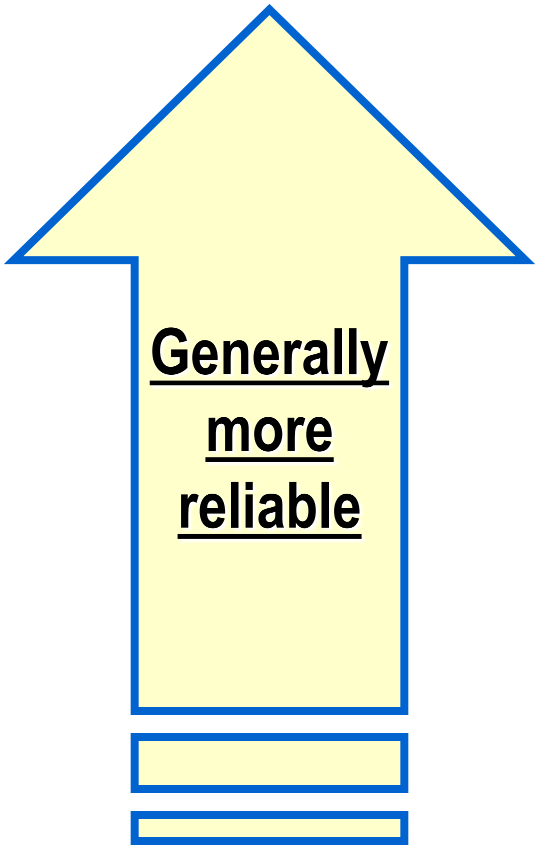
Chemical Process Hazards

Chemical process hazards come from two sources:

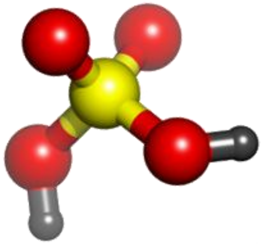
- Chemistry hazards - flammability, toxicity, reactivity
- Process hazards - pressure, temperature, concentration



Four process safety strategies



- **Inherent** – Eliminate the hazard by using non-hazardous materials and process conditions
- **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 – Eliminate the hazard by using non-hazardous materials and process conditions
- Passive - Process or equipment design features that reduce risk without active functioning of any device
- Active - Engineering controls
- Procedural - Administrative controls

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DISCUSSION

What are a couple of examples of each strategy?

- Inherent – Substituting water for a flammable liquid as a solvent
- Passive – Robust pressure vessel design or blast resistant construction
- Active – a pump that is shut off by a high level switch when the tank is 90% full
- Procedural – hot work permitting or emergency plans

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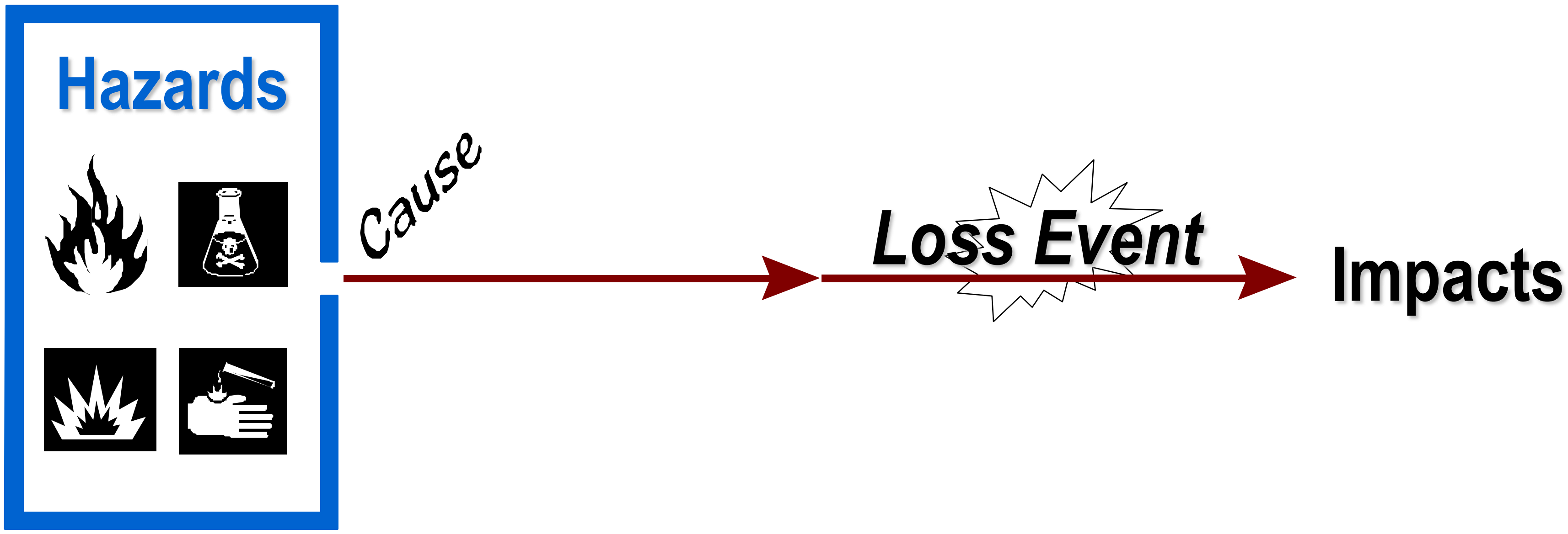
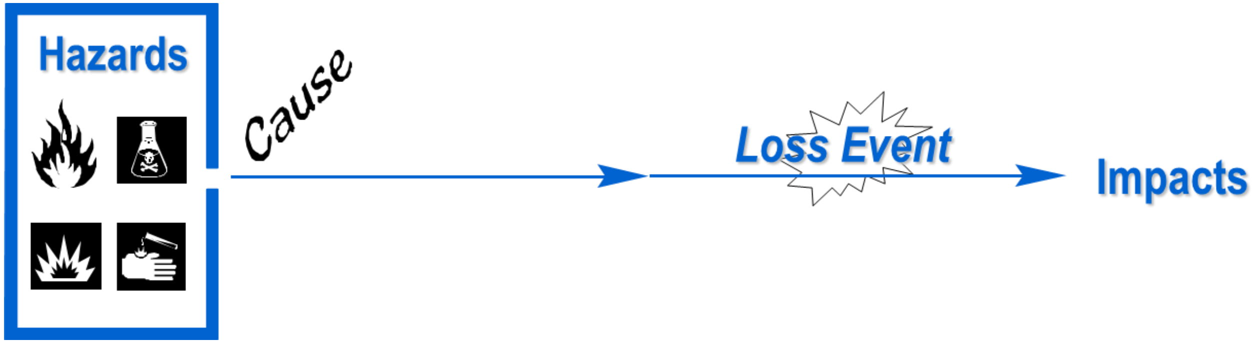
One more vantage point

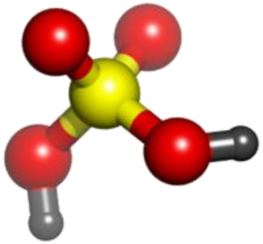
Reducing the underlying hazards...



One more vantage point

… can reduce potential loss event impacts.





Inherently Safer Design

1. What is "inherently safer design"?
2. Why is it important?
3. **What are the basic inherently safer strategies?**
4.
5.
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7.

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Inherent safer design strategies

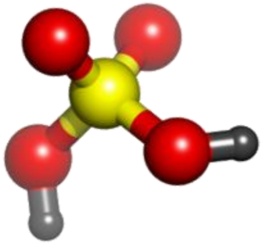
Focus in this course:

Minimize

Substitute

Attenuate

Simplify



Inherent safer design strategies

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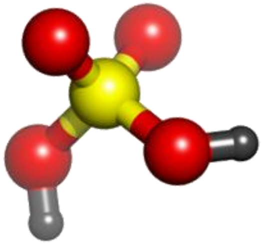

Look back – ISD definition

ISD 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.

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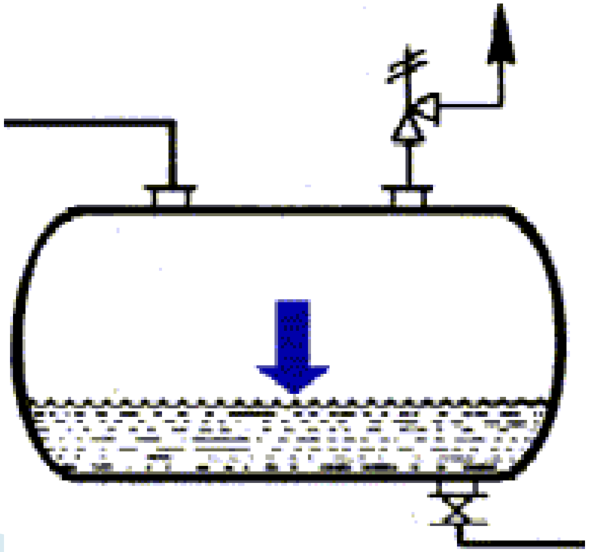
Minimize

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.



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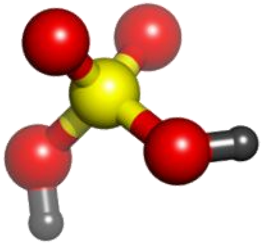
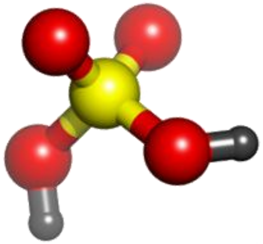


Minimize

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***:

- <u>Inventory reduction</u>; 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:

- <u>Elimination</u> 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*)
    - Another company produces product for your company for a fee

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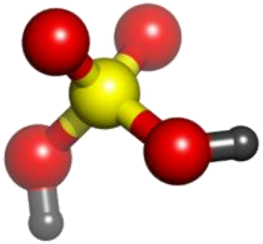
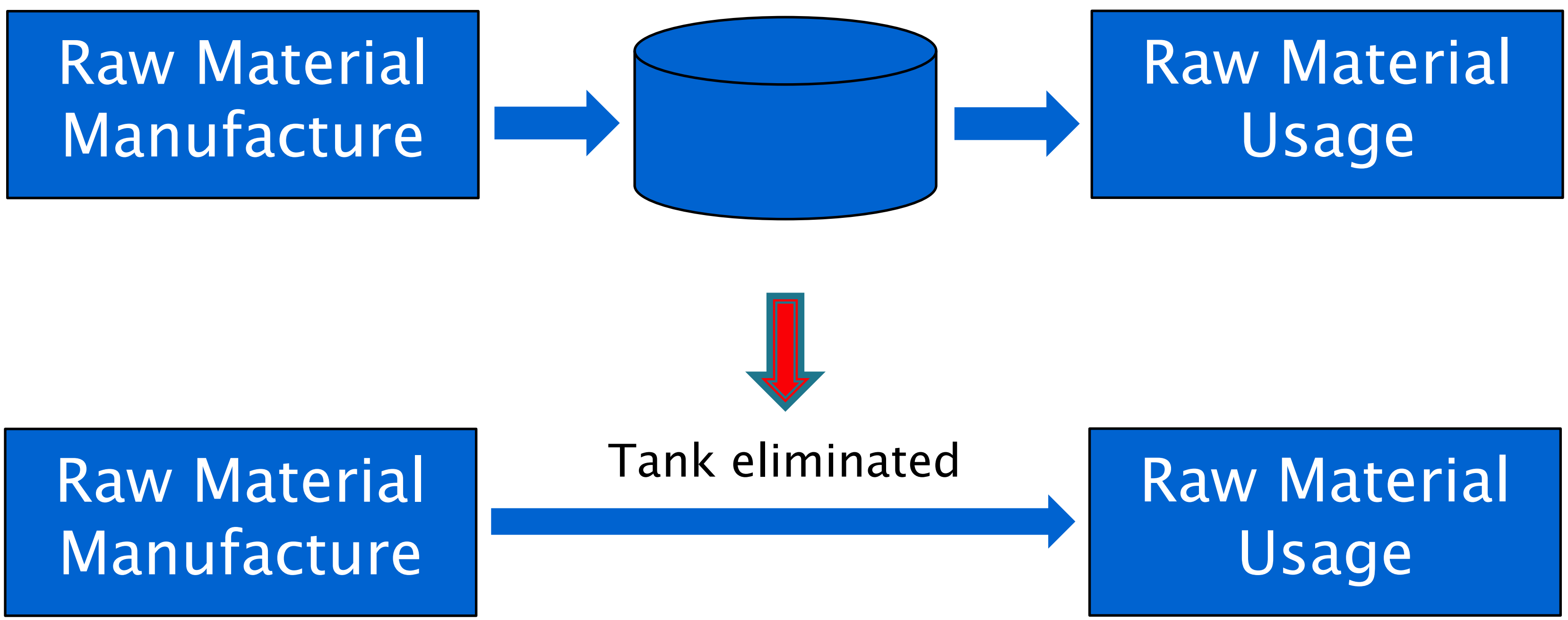
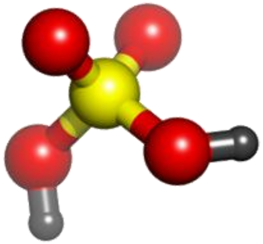


DISCUSSION

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

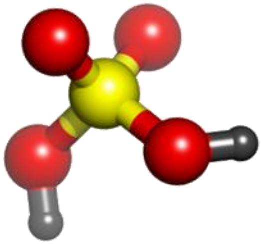




DISCUSSION

Raw Material Manufacture → **Raw Material Usage**

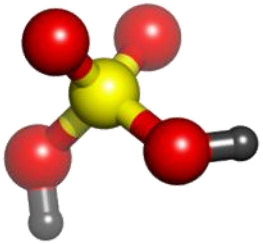
- What are the inherent safety <u>benefits</u>?
- What are the possible <u>drawbacks</u>?



DISCUSSION

Raw Material Manufacture → Raw Material Usage

- What are the inherent safety benefits?
  - Less hazardous material on-site
  - Reduction in number of tanks that requires upkeep and maintenance
- What are the possible drawbacks?
  - Supply limited if plant production has problems
  - Quality of supplied material could have fluctuations in quality



Inherent safer design strategies

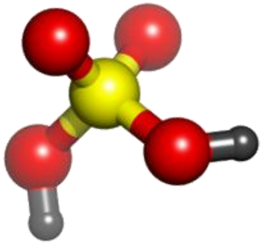
Focus in this course:

Minimize

Substitute

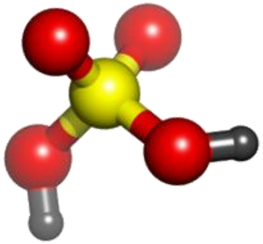
Attenuate

Simplify



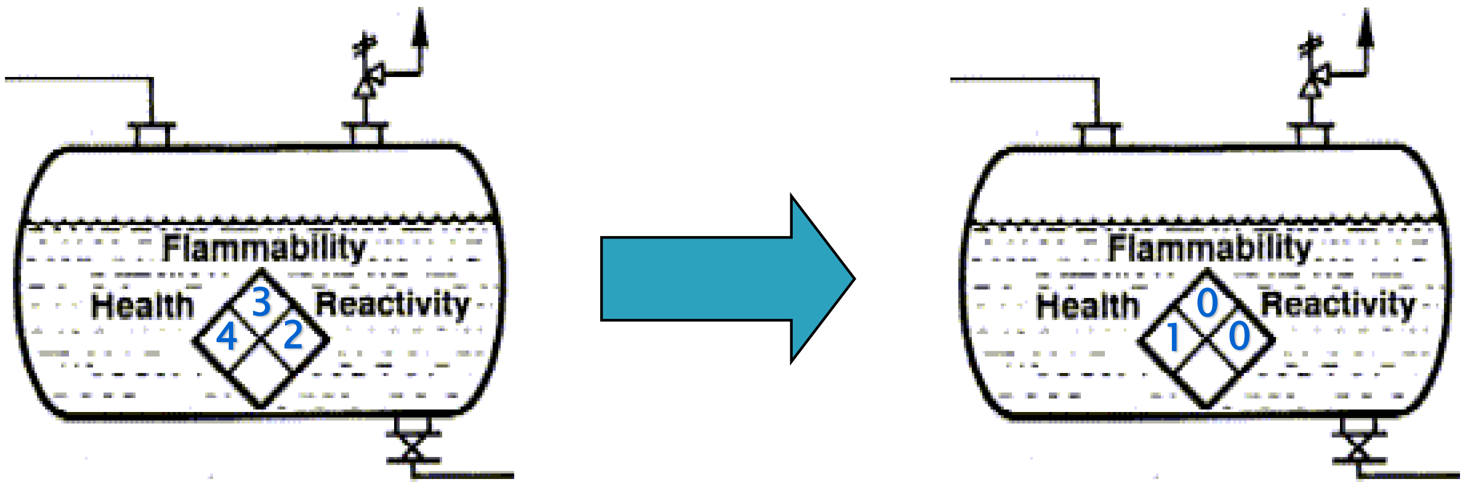
Look back – ISD definition

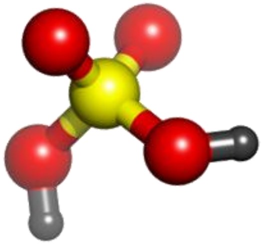
ISD is an iterative process that considers such options including: eliminating a hazard, reducing a hazard, **substituting a less hazardous material**, using less hazardous process conditions, and designing a process to reduce the potential for, or consequences of, human error, equipment failure, or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

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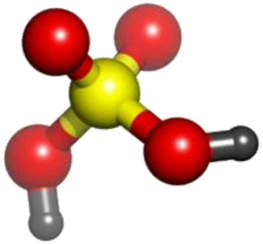
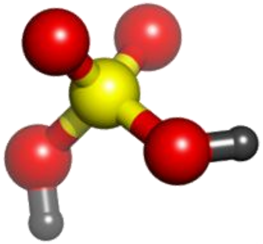


Substitute

Some chlorine alternatives: *Cl_2*

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



Substitute

Some chlorine alternatives:

Cl_2

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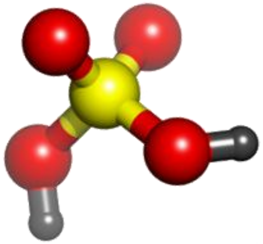

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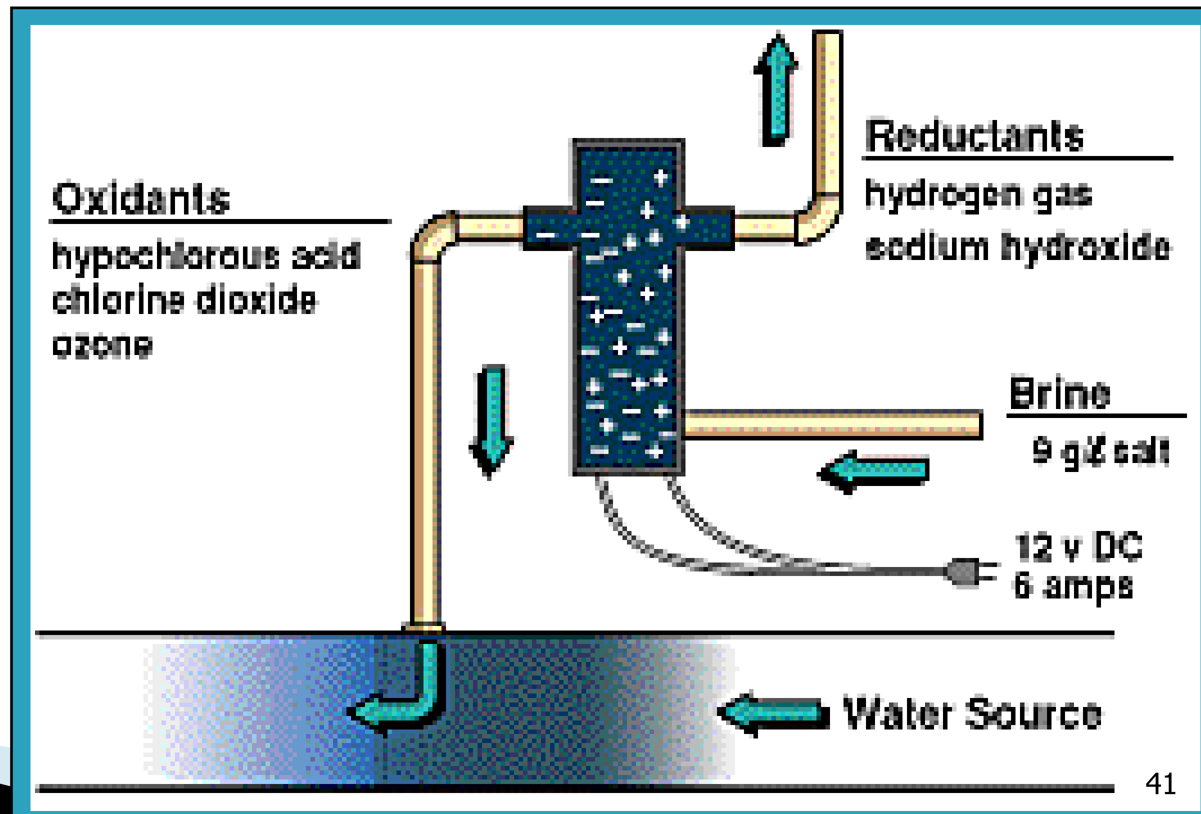

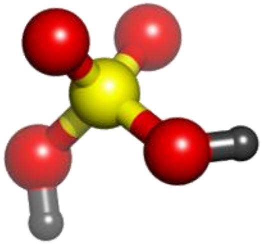

Substitute

<u>Oleum</u> (fuming sulfuric acid) sulfonating agent

- low cost for SO3 however large quantities of unreacted sulfuric acid left behind and disposal cost is very expensive

alternative:

- Sulfur burning to generate SO_3 on demand

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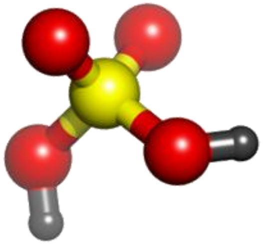

Substitute

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," www.epa.gov/ozone/snap/solvents/solvents.pdf

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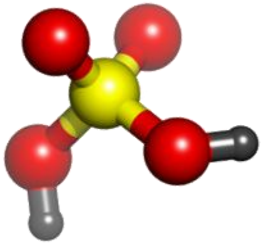

Inherent safer design strategies

Focus in this course:

Minimize

Substitute

Attenuate

Simplify

CSP
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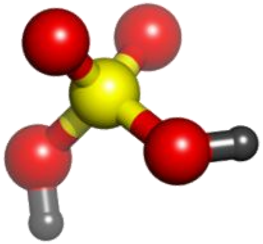

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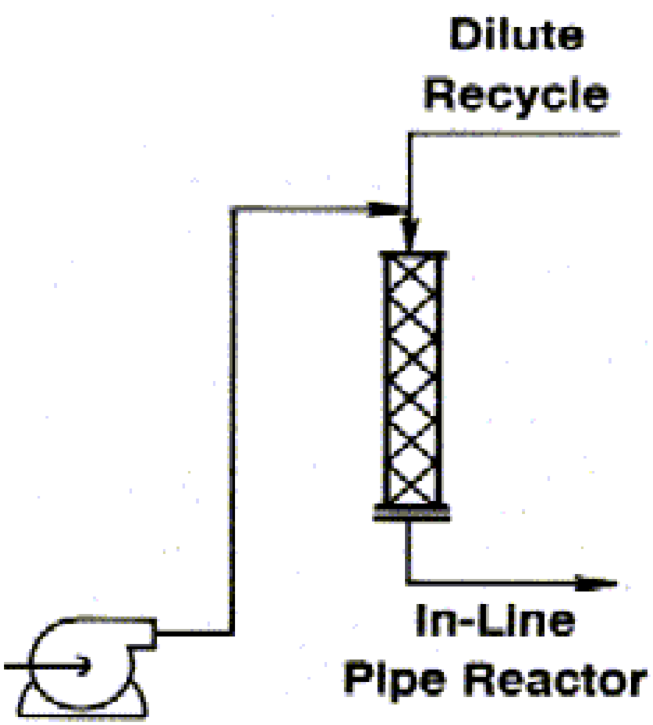
Attenuate

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



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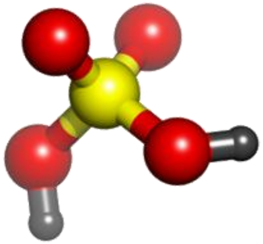
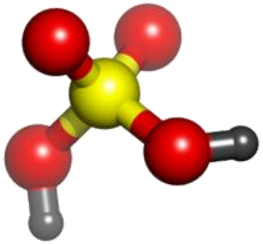


Attenuate

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 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

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4. What are some other related strategies?
5.
6.
7.

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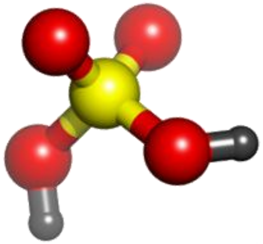

Look back – ISD definition

ISD 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.**

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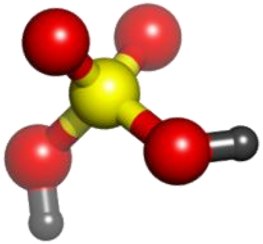


Inherent safer design strategies

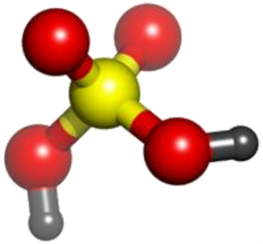
Focus in this course:

Minimize

Substitute

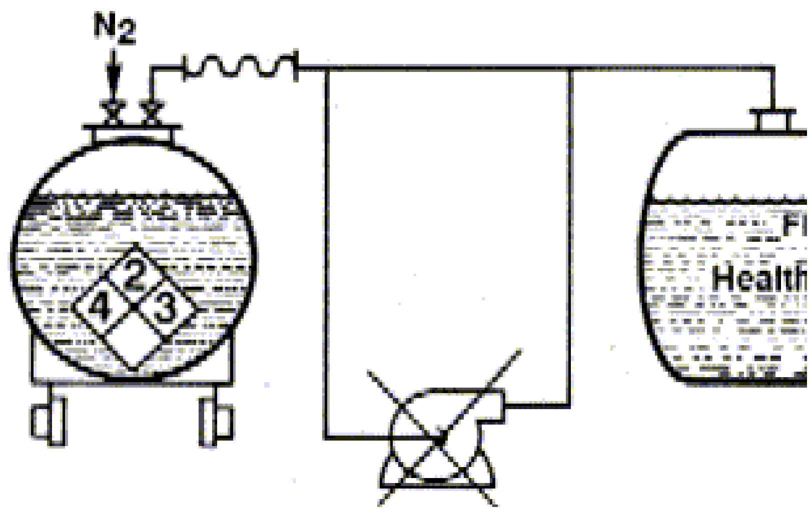
Attenuate

Simplify



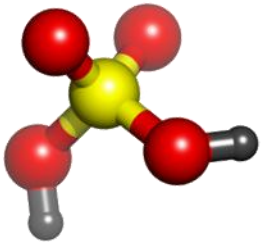
Simplify

To ***simplify*** is to eliminate unnecessary complexity.



Elimination of Pump

- Possibly switching to gravity feed



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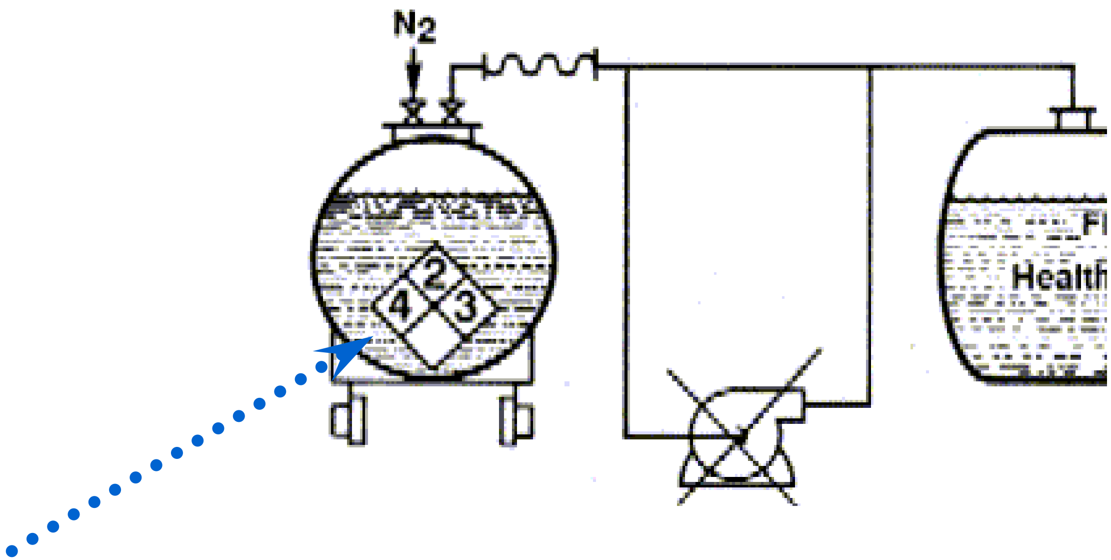
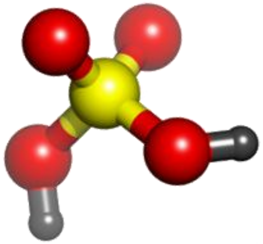


(<u>Not</u> “first-order” inherent safety, since the underlying hazard is still there.)



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

Industrial Example

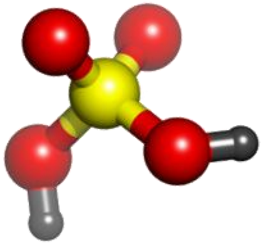
Dow Chemical's purchase of a Phosgene plant in Portugal

Background:

Dow chemical bought a urethanes business from a company in Europe, consisting of two major installations in Portugal and the Netherlands. The Portuguese plant was of concern due to large scale production and use of Phosgene. Due to little experience with Phosgene, Dow established a team to make a plan for managing the new risk.

$$\text{Main Reaction}: \quad CO + Cl_2^{\text{liquid}} \xrightarrow{\textit{catalyst}} COCl_2$$

Produced phosgene was then distilled to remove impurities and then passed into a reaction system which included the solvent monochlorobenzene and aniline producing polymeric methylene diphenyl diisocyanate (MDI) that was shipped away for further refining. Used in the production of polyurethanes.



Industrial Example Cont'd

Qualitative Risk Assessments:

<u>Fire & Explosion Index</u>: calculated based on the flammability and explosion potential of materials inventory and process severity

<u>Chemical Exposure Index</u>: calculated based on toxicity, inventory, volatility of materials and process severity – primarily as might affect the neighbors inside and outside the property line

- Fire Explosion Index had been around for 20+ years
- Chemical Exposure Index had only been around <10years – after Bhopal

Findings:

- Chemical Exposure Index was 60% higher than any other operation Dow had in Europe
- Significant risk was the liquid chlorine pipeline

Industrial Example Cont'd

Minimize:

Liquid Chlorine Inventory

- Pipeline operated at 8 bar with liquid chlorine
- 7500kg of liquid chlorine located in the pipe run alone

Conversion to chlorine gas

- Reduced amount of chlorine in pipe run by 90%
- New pipeline constructed with an outer containment equipped with leak detection

Supplier renegotiation

- Provide much purer CO

Industrial Example Cont'd

Substitution:

Heating and cooling

- Done with shell and tube heat exchangers with steam or water
- Inadequate drying of process pipe-work led to corrosion which eventually allowed water into the process
- Corrosion tearing up seats and the internals of bellows of sealed valves

Eliminating water and steam as direct heating and cooling media

- Monochlorobenzene chosen as barrier fluid
- Freon 114 chosen as cooling solvent
- These fluids were then heated and cooled by cooling water and steam

Equipment replacement possible because of corrosion issue controlled

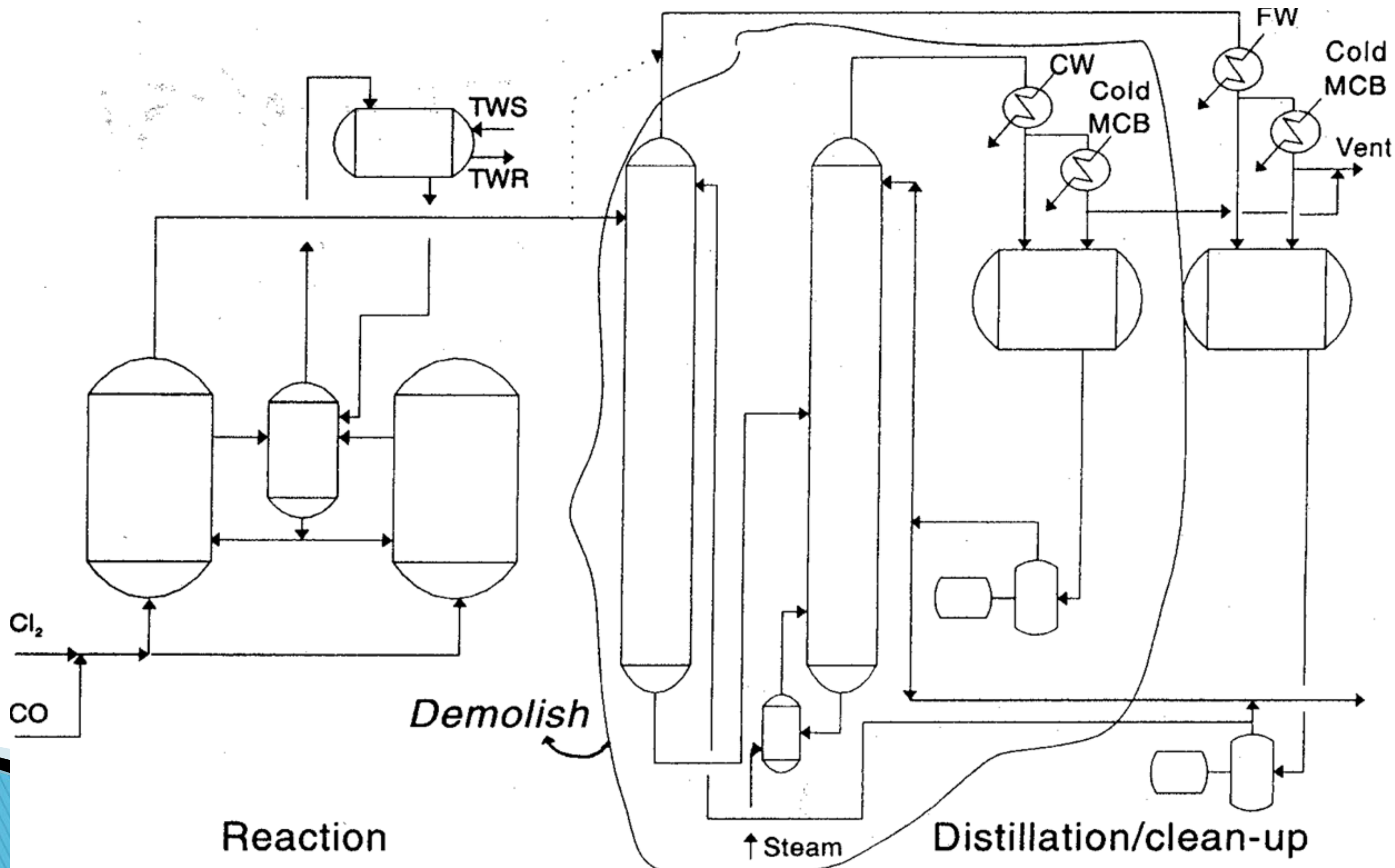
- Old - Centrifugal pumps with mechanical seals and standard ball, gate, and globe valves with conventional stem seals
- New - Bellows-sealed valves and magnetically driven pumps

Industrial Example Cont'd

Applying Inherently Safer Concepts to a Phosgene Plant Acquisition – Richard Gowland, Dow Chemical

Simplification:

Purer supply of CO led to plant's cleaning system redundancies



Industrial Example Cont'd

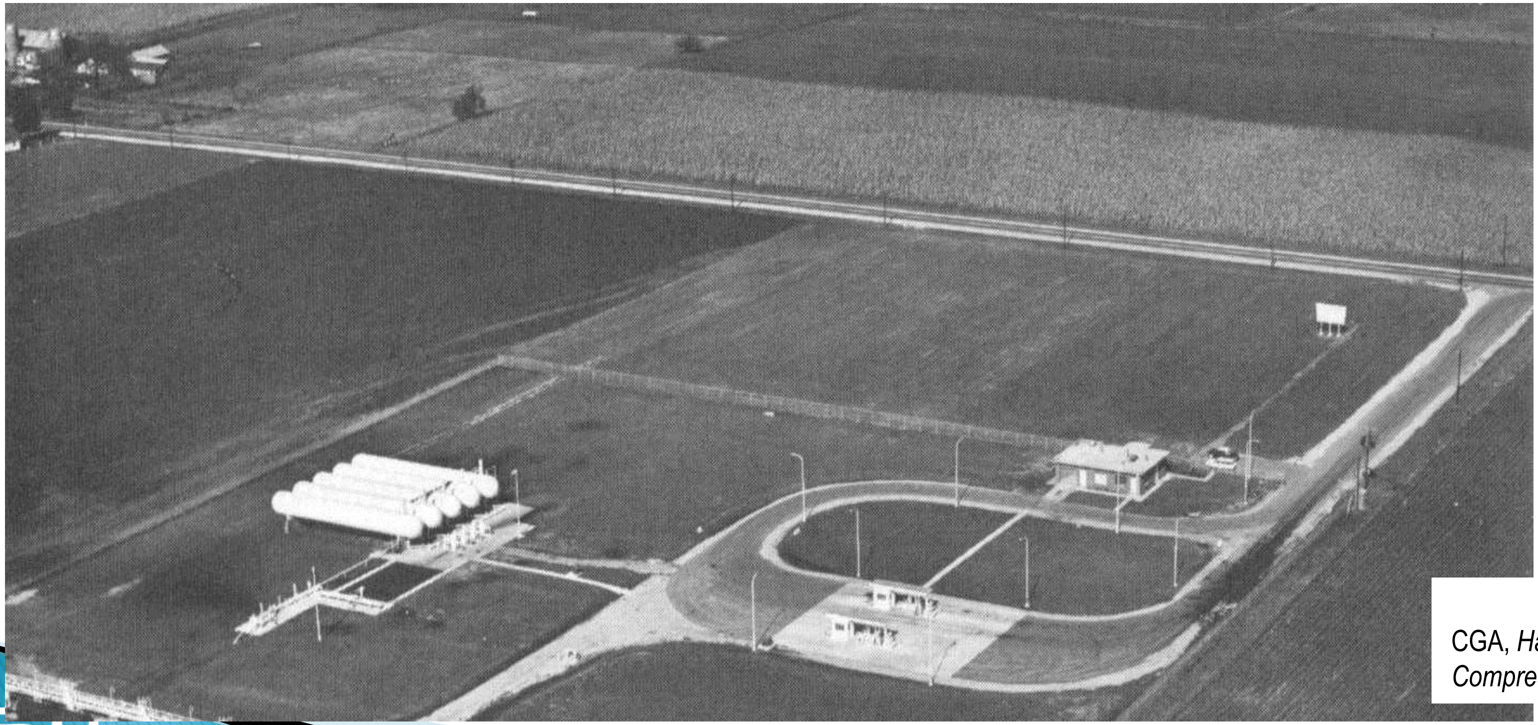
Results:

- Return of investment of 46%
- Dramatic reduction in frequency and size of leaks
- Large reduction in inventory and resultant hazard potential
  - Largest single inventory reduced form 50 to 1 metric ton
- Risk to the general public reduced several orders of magnitude
- Cheaper plant economics
  - Conversion cost
  - Yield
  - Reduced maintenance cost
  - Improved productivity

Applying Inherently Safer Concepts to a Phosgene Plant Acquisition – Richard Gowland, Dow Chemical

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

1. What is “inherently safer design”?
2. Why is it important?
3. What are the basic inherently safer strategies?
4. What are some other related strategies?
5. How is it implemented in a facility's life cycle?

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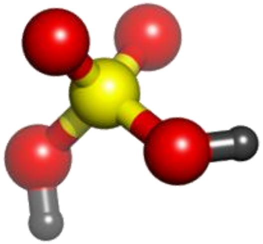
Look back – ISD definition

- **ISD** is a philosophy, **applied to the design and operation life cycle**, including manufacture, transport, storage, use, and disposal.

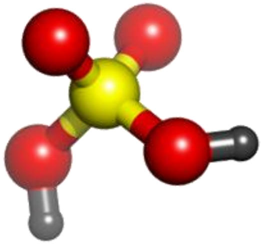
- **ISD** is an **iterative process** that considers such options including: eliminating a hazard, reducing a hazard, substituting a less hazardous material, using less hazardous process conditions, and designing a process to reduce the potential for, or consequences of, human error, equipment failure,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



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]

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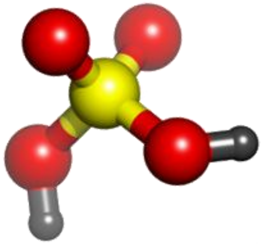
Inherent safety reviews

Most effective life cycle phases to review a 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

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Inherent safety reviews

Good resource for ISD reviews (CCPS 2008a, 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

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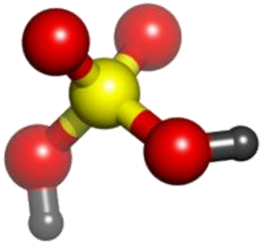

Inherently safer design

1. What is “inherently safer design”?
2. Why is it important?
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4. What are some other related strategies?
5. How is it implemented in a facility's life cycle?
6. What are some limitations of inherently safer?

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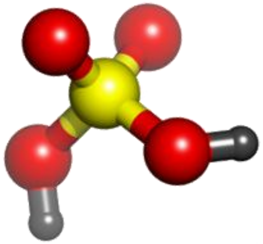


CAUTION

Inherently Safer does not necessarily mean *lower* ***risk***!

- Process change may introduce new hazards

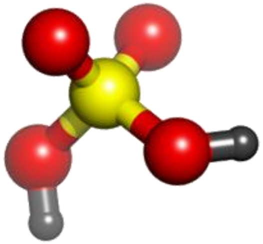
  (**e.g.** hydrogen gas generated by hydrolysis)

- 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* ?

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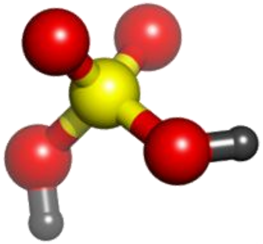
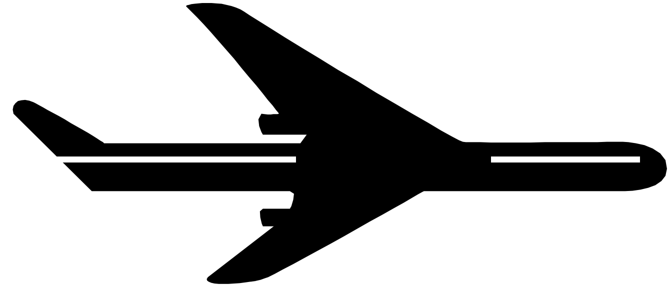


Airline travel



HAZARDS:

- **Potential energy** (10.3 km altitude; heavy objects in overhead bins)
- **Kinetic energy** (970 km/hr; 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)

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Inherently Safer Design

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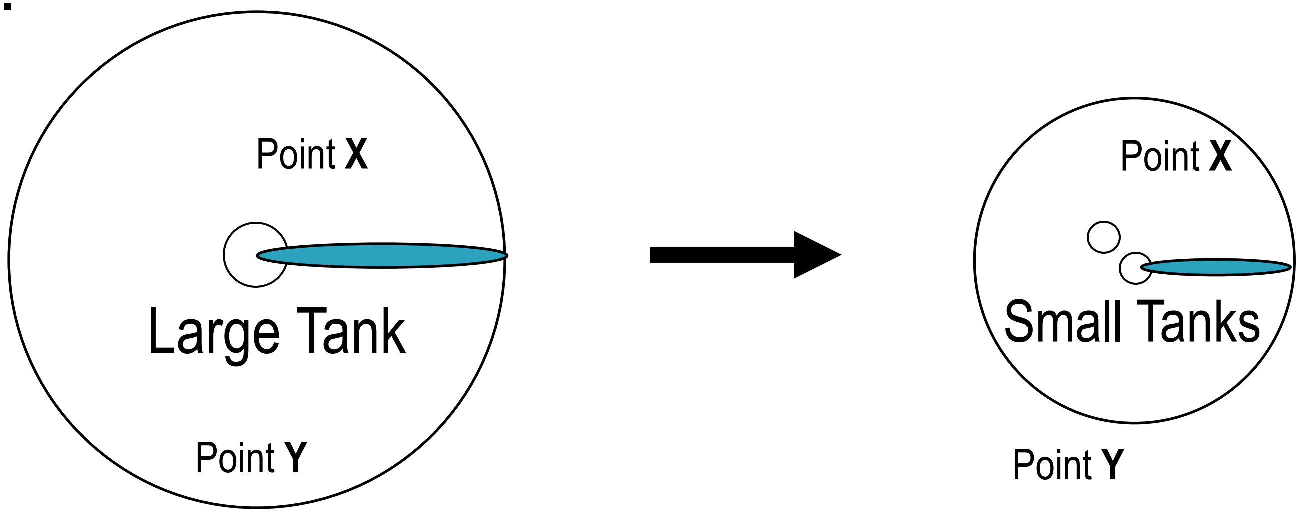
7. **Class discussion and exercise**

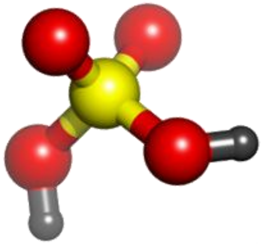
DISCUSSION: Volatile toxic liquid storage

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.



Point **Y** now outside contaminated area



EXERCISE

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

2 Identify at least three specific ideas for making the process <u>inherently safer</u>

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

WRAP-UP DISCUSSION

- What are some major challenges to implementing inherently safer principles?
- How might these be overcome?

WRAP-UP DISCUSSION

Do inherently safer principles also apply to *facility security*?

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