AcuTech
Process Risk Management

Inherently Safer Design Analysis Approaches

There are a number of ways inherent safety can be analyzed. In any case, the intent is to formalize the consideration of inherent safety rather than to include it by circumstance. By formally including inherent safety in either a direct or indirect way, the potential benefits of inherent safety may be fully realized and considerations of inherent safety are documented.

Three methods can be employed:

1. Inherent Safety Analysis – Checklist Process Hazard Analysis (PHA)
2. Inherent Safety Analysis - Independent Process Hazard Analysis (PHA)
3. Inherent Safety Analysis – Integral to Process Hazard Analysis (PHA)

For 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. (See the complete checklist in Appendix C – this is a representative subset only to illustrate use of the checklist). The advantage of this approach is that it is very direct and asks pointed questions that have proven to be valuable in reducing hazards at past locations. The disadvantage is that, as with any checklist, it may be limiting in that other ideas may surface if the team was asked to more creatively determine applications for the inherent safety strategies given a safety objective.

For the second method, the team is asked to avoid a particular hazard at a part of the process. In that case the 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.

The third method is to 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.

Each method is explained below.

In all cases it is recommended to use a risk ranking scheme which defines likelihood and consequences on a scale such as the one shown on Tables 1-3. Inherent safety should be considered in light of risks as with other risk management strategies.

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			

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)	$	$$	$$$	$$$$
Business interruption (days unavailable or $)	$	$$	$$$	$$$$
Environmental impact (remediation damages)	$	$$	$$$	$$$$

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

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

Figure 1 is an example of a checklist approach. The analyst reviews the potential for applying inherent safety either at entire process level or at the node level, where a node is defined similarly to Process Hazards Analysis studies or is the same node as existing studies. It is possible to do the analysis at a higher level was required for PHA study if the process is relatively simple and the ISD opportunities are limited. If the study is conducted at a detailed node level is may result in additional considerations being given to smaller but important details. For example, at a macro level the hazardous chemical in the process cannot be substituted, but on a micro level there may be opportunities to do so at given areas or items of equipment.

The analyst asks the question of the checklist (potential opportunities) and the team documents the potential consequences of the issue that may be applicable to the process or node under study. Considering the four ISD strategies, the team documents the potential recommendations that may address the concern using the order of First Order ISD, Second Order ISD, followed by Layers of Protection.

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

Location: Orange, New Jersey						**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.[1]	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[2]	In review
3	Reducing finished product inventory	Not applicable (NA)[3]								
4	Reduce hazardous material by using alternate equipment		No alternatives available or feasible[4]							

[1] Note: This uses the concept of ***Minimization*** to avoid a hazard. The feed was previously planned to be taken from any of five tanks vs. the process could be managed with only three tanks. A hazardous condition was reduced so this represents a **Second Order Inherent Safety** change.
[2] Note: This uses the concept of ***Minimization*** to avoid a hazard. There was planned in unit tanks that possibly could be eliminated. A hazardous condition was eliminated so this represents a **First Order Inherent Safety** change
[3] Note: Some questions are not relevant to the particular process.
[4] Note: Some questions may result in a conclusion that there are no alternatives or feasible inherent safety application.

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

Location: Orange, New Jersey **PFD No.:** 1234-5678 **Node::** Isobutane Storage **Design Conditions/Parameters:** Storage of isobutene in five bullets and two process vessels near the unit						**Risk Ranking**			**Unit**: Hydrofluoric Acid Alkylation unit	**Analysis Date:** April 1, 2008
	QUESTION	**POTENTIAL OPPORTUNITIES**	**FEASIBILITY**	**CONSEQUENCES**	**EXISTING SAFEGUARDS**	**S**	**L**	**R**	**RECOMMENDATIONS**	**COMMENTS/STATUS**
5	Minimize length of hazardous material piping runs	There are many piping runs that are no longer used that might be decommissioned.	Need to consider in engineering and operations evaluation but appears to be feasible.	Potential larger release		4	1	3	3. Consider moving the location of the planned storage vessels to a location not closer than 250 feet but closer than the 1500 feet location presently planned.[5]	
6	Smallest diameter piping	The line planned for the feed is oversized and could contain a larger inventory than is necessary.	Possible following engineering evaluation to reduce diameter.	Potential larger release		3	2	3	4. Reduce the planned feed line size from 6 to 4 inch[6]	
7	Eliminate hazardous raw materials, process intermediates, or by-products by using an alternative process or chemistry		No alternative for isobutane in the process[7]							
8	Eliminate in-process solvents and flammable heat transfer media.	Substitute the flammable solvent.	A nonflammable solvent may be commercially available.	Possible source of flammable release	Existing fire prevention controls and fire suppression systems.	3	3	4	5. Consider substituting the solvent used with a non-flammable solvent.[8]	

[5] Note: This uses the concept of ***Minimization*** to avoid a hazard. There was planned in unit tanks that possibly could be eliminated. A hazardous condition was eliminated so this represents a **First Order Inherent Safety** change.
[6] Note: This uses the concept of ***Minimization*** to avoid a hazard. There was planned in unit tanks that possibly could be eliminated. A hazardous condition was eliminated so this represents a **First Order Inherent Safety** change.
[7] Note: Some questions may result in a conclusion that there are no alternatives or feasible inherent safety application.
[8] Note: This uses the concept of ***Substitution*** to avoid a hazard. There was planned a flammable solvent when a nonflammable alternative solvent was available. A hazardous condition was eliminated so this represents a **First Order Inherent Safety** change.

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

Location:						**Risk Ranking**			**Unit**:	**Analysis Date:**
PFD No.:										
Node::										
Design Conditions/Parameters:										
	QUESTION	**POTENTIAL OPPORTUNITIES**	**FEASIBILITY**	**CONSEQUENCES**	**EXISTING SAFEGUARDS**	**S**	**L**	**R**	**RECOMMENDATIONS**	**COMMENTS/STATUS**
1	Reduce hazardous raw materials inventory									
2	Reducing in-process storage and inventory									
3	Reducing finished product inventory									
4	Reduce hazardous material by using alternate equipment									
5	Minimize length of hazardous material piping runs									
6	Smallest diameter piping									
7	Eliminate hazardous raw materials, process intermediates, or by-products by using an alternative process or chemistry									

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

Location:						**Risk Ranking**			**Unit**:	**Analysis Date:**
PFD No.:										
Node::										
Design Conditions/Parameters:										
	QUESTION	**POTENTIAL OPPORTUNITIES**	**FEASIBILITY**	**CONSEQUENCES**	**EXISTING SAFEGUARDS**	**S**	**L**	**R**	**RECOMMENDATIONS**	**COMMENTS/STATUS**
8	Eliminate in-process solvents and flammable heat transfer media.									

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

Figure 2 is an example of an ISD approach which is similar to a typical PHA but focuses exclusively on ISD. The analyst reviews the potential for applying inherent safety either at entire process level or at the node level, where a node is defined similarly to Process Hazards Analysis studies or is the same node as existing studies. It is possible to do the analysis at a higher level was required for PHA study if the process is relatively simple and the ISD opportunities are limited. If the study is conducted at a detailed node level is may result in additional considerations being given to smaller but important details. For example, at a macro level the hazardous chemical in the process cannot be substituted, but on a micro level there may be opportunities to do so at given areas or items of equipment.

The analyst considers a hazard, such as runaway reaction caused by water reactivity in a reactor, and sets a safety objective – 'Minimize potential for runaway reaction in the feed to the reactor'. The team then documents each potential cause of the hazard being realized and reviews the consequences, existing safeguards, and potential means of eliminating the hazard or reducing the risk through ISD strategies.

Considering the four ISD strategies, the team documents the potential recommendations that may address the concern using the order of First Order ISD, Second Order ISD, followed by Layers of Protection. Each strategy is considered and ideas are generated that are feasible and practical, and that adequately and best address the hazard. It could be that other risk management strategies besides ISD are more effective.

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.[9]	
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. Excess water in	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.[10]	
		2. Operator training 3. Temperature instrumentation to					There is an excess number of	3. Reduce the number of water cross connections to the	

[9] Note: This uses the concept of ***Substitution*** to avoid a hazard. The feed was previously taken from a tank that had water contaminants that had to be controlled vs. the alternative tank did have this inherent condition. A hazardous condition was avoided altogether so this represents a **First Order Inherent Safety** change.

[10] Note: This uses the concept of A***pplying Procedural Safeguards*** to avoid a hazard. The operating procedure wasn't explicit on checking these aspects which may reduce the likelihood of the water being mistakenly left on but the inherent condition of water usage and lead potential still exists but the likelihood, and therefore the risk, may have been reduced.

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
	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.	monitor reaction rate					cross connections so some can be eliminated.	feed to the reactor from 3 to 1.[11]	

[11] Note: This uses the concept of ***Minimization*** to avoid a hazard. The water wash was previously done from a multiple connections vs. the alternative approach of eliminating unnecessary connections to reduce the likelihood of the incident. The likelihood of the hazardous condition was reduced through elimination of equipment so this represents a **Second Order Inherent Safety** change.

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

Node: 1.
Objective: 1.

CAUSES	CONSEQUENCES	EXISTING SAFEGUARDS	S	L	R	OPPORTUNITIES	FEASIBILITY	RECOMMENDATIONS	COMMENT//STATUS

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

Figure 3 is an example of an ISD approach which is similar to a typical PHA but focuses exclusively on ISD. The analyst reviews the potential for applying inherent safety either at entire process level or at the node level, where a node is defined similarly to Process Hazards Analysis studies or is the same node as existing studies. It is possible to do the analysis at a higher level was required for PHA study if the process is relatively simple and the ISD opportunities are limited. If the study is conducted at a detailed node level is may result in additional considerations being given to smaller but important details. For example, at a macro level the hazardous chemical in the process cannot be substituted, but on a micro level there may be opportunities to do so at given areas or items of equipment.

The analyst considers a hazard, such as runaway reaction caused by water reactivity in a reactor, and sets a safety objective – 'Minimize potential for runaway reaction in the feed to the reactor'. The team then documents each potential cause of the hazard being realized and reviews the consequences, existing safeguards, and potential means of eliminating the hazard or reducing the risk through ISD strategies.

Considering the four ISD strategies, the team documents the potential recommendations that may address the concern using the order of First Order ISD, Second Order ISD, followed by Layers of Protection. Each strategy is considered and ideas are generated that are feasible and practical, and that adequately and best address the hazard. It could be that other risk management strategies besides ISD are more effective.

Note that the only difference from Method 2 is the way in which the hazard is identified (in this example a HAZOP method utilizes deviations from design intent) vs. in method 2 the hazard was recognized and directly addressed by ISD. The way in which ISD is considered remains the same (the ISD hierarchy of analysis of First Order ISD, Second Order ISD, followed by Layers of Protection applies no matter what the analysis method unless the scope is limited to only identify ISD potential recommendations).

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.[12]	
2. 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.. 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	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.[13]	
		2. Operator training					There is an excess number of cross connections	3. Reduce the number of water cross connections to the feed to the reactor from 3 to 1.[14]	

[12] Note: This uses the concept of ***Substitution*** to avoid a hazard. The feed was previously taken from a tank that had water contaminants that had to be controlled vs. the alternative tank did have this inherent condition. A hazardous condition was avoided altogether so this represents a **First Order Inherent Safety** change.

[13] Note: This uses the concept of A***pplying Procedural Safeguards*** to avoid a hazard. The operating procedure wasn't explicit on checking these aspects which may reduce the likelihood of the water being mistakenly left on but the inherent condition of water usage and lead potential still exists but the likelihood, and therefore the risk, may have been reduced.

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
	reaction.						so some can be eliminated.		
		3. Temperature instrumentation to monitor reaction rate							

[14] Note: This uses the concept of ***Minimization*** to avoid a hazard. The water wash was previously done from a multiple connections vs. the alternative approach of eliminating unnecessary connections to reduce the likelihood of the incident. The likelihood of the hazardous condition was reduced through elimination of equipment so this represents a **Second Order Inherent Safety** change.

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

Node: 1.
Intent: 1.
Guideword: **Parameter:** **Deviation:**

CAUSES	CONSEQUENCES	EXISTING SAFEGUARDS	S	L	R	OPPORTUNITIES	FEASIBILITY	RECOMMENDATIONS	COMMENT/STATUS