Incorporating Inherently Safer Technology into a Corporate Risk Management Program

A.M. (Tony) Downes, Global Process Safety Advisor, David Prior, Director of Process Safety & Loss Prevention, Pascal Bolomey, Sr Director R&D, Noel Misa, Principal Process Safety Engineer, Honeywell (Performance Materials & Technologies), 115 Tabor Rd, Morris Plains NJ, 07950 USA

For many years, Honeywell has managed its process safety hazards through a robust program of hazard identification and risk analysis. More than ten years ago, we added an Inherently Safer Technology (IST) component to our risk management program. For practical reasons, our efforts focused on new capital projects. This paper will describe several evolutions in our efforts to institutionalize the IST thought process, and to drive from the application of IST in small changes later in the design process towards the application of IST to the fundamental process in Research and Development. It will discuss why we focused on new projects – in line with the strategy suggested by Trevor Kletz (who first coined the phrase "IST") many years ago. It will point out the practical steps such as training for our process designers and project leaders. It will point out how we are now extending IST reviews upstream in partnership with R&D. And we'll review specific practical issues and lessons learned along the way, such as selecting effective IST chemistries early on, as well as how to document IST "safeguard features" within our Hazard Review process so they can be identified and will not be forgotten over the years.

Keywords: Inherently Safer Technology, IST

Introduction

For many years, Honeywell has managed its process safety hazards through a robust program of hazard identification and risk analysis. As we looked at our risks more quantitatively, and applied good engineering practices like IEC-61511 we found it appropriate to install more SIL-rated active safeguards. These were effective, and worked well, but at a substantial cost – both capital cost to install and operating cost to maintain, not to mention the cost of the occasional spurious trip.

Several factors came together to trigger foresighted engineering leaders to look at the way we were managing risks with add-on active safeguards. These included the recognition that the most economical leverage for risk management is at the beginning of the design process, when safety can ideally be built into the fundamental process design, rather than waiting to add layers of protection at the back end of the design process. Several large projects were running in parallel, emphasizing the need for cost-effective risk reductions to conserve capital.

Another factor was that the reaction conditions for some of our newer materials were requiring higher temperatures. Where the reaction was occurring in the liquid phase, this meant the pressures also had to be higher. Thus, the possible mass flow rate from a nominal size leak was getting potentially larger and larger. The Process Safety team in Engineering couldn't do anything about this, so they reached out to R&D to explain the issue and warn about the implications of this trend.

This paper will describe several evolutions in our efforts to institutionalize the IST thought process. To refresh, the four IST strategies and the intention of each strategy are as follows

1. Substitute/Eliminate - Replace a material with a less hazardous substance
2. Moderate - Use less hazardous conditions, a less hazardous form of a material, or facilities which minimize the impact of a release of hazardous material or energy (also called Attenuation and Limitation of Effects).
3. Minimize - Use smaller quantities of hazardous substances (also called Intensification)
4. Simplify - Design facilities which eliminate unnecessary complexity and make operating errors less likely, and which are forgiving of errors which are made (also called Error Tolerance).

Applying IST during Equipment Design Phase FEL-3 (The "Micro" approach)

More than ten years ago, Honeywell added an Inherently Safer Technology (IST) component to our risk management program. As our first organized foray into IST, we developed a large checklist of questions based on Center for Chemical Process Safety (CCPS) and other documents. The idea was that it could be used during Process Hazards Analyses – either for new projects, or in revalidations. And we wrote a Procedure for its use. But it had very limited success. Looking back, there were some issues:

- The list of questions was too long to be used as a regular checklist for each "node." It was also generically applied.
- The list had some questions that really didn't make sense to ask during the project design. For example, the first question was: "Is this (hazardous) product/process necessary?" It would have been difficult to answer No at that stage.

We found that a better approach was to have questions targeted for each stage in development. That is, broad, high-level process selection/substitution questions are asked during early R&D phases and much more specific questions about equipment design are asked during the Process Design Phase in the "Front End Loading (FEL)" second stage, or FEL-2 (see also the Glossary section at the end of the Paper). See Figure 2 for the development phases and associated IST activities.

Focused Use on Major Capital Projects

In our first efforts, we required all our hazard review teams – even the ones doing revalidations - to discuss ways to manage risk by reducing inherent hazards. As Trevor Kletz pointed out many years ago, this isn't a particularly effective time to make substantial changes to designs. "Many decisions about inherent safety have to be made early in design. It is too late to tell the builder when our house is complete that we do not want any stairs; it is too late to tell the architect when the drawings are complete." (Kletz) We soon learned that the best opportunity for IST was during new projects. We created a new IST study step to use at the Block Flow/PFD phases (FEL-1). We used simplified IST checklists – tailored to this stage of the project – and a sort of "What If" type team review that looked at the major process steps and imagined what hazards were present at each step. The checklists were used by the team as memory joggers of possible IST solutions to reduce those hazards.

We conducted training on IST principles for our process designers and project leaders. After a while we found they tended to develop inherently safer process designs when they could as a matter of course because they knew to think about hazards and how these might be eliminated or controlled by Inherent or Passive safeguards.

One novel approach to kick-start the IST thought process was to add a measurable target for its use. We focused only on the highest consequence hazards as identified in our Risk Matrix by HAZOP teams. And we added a target for the process engineers and the HAZOP teams. We asked that they recommend an Inherently Safer Technology/Design option for at least 10% of those "large" hazards. We didn't commit to choosing that option, as sometimes they were impractical. But, the process engineers were starting to think about hazards and how to reduce them using IST.

This had several successes. In one example, we eliminated a pipe-leak hazard by combining a reboiler into the bottom of a distillation column rather than having it external. This pipe had been a significant contributor to the overall risk in the quantified risk analysis because it was large, hot (above atmospheric boiling point) and high pressure. This is often the case, as the "average" leak frequencies from pipes are much higher than the leak frequencies from pressure vessels. Thus, we had a clear indication that the combined-reboiler design was inherently safer in this case. (See Fig 1)

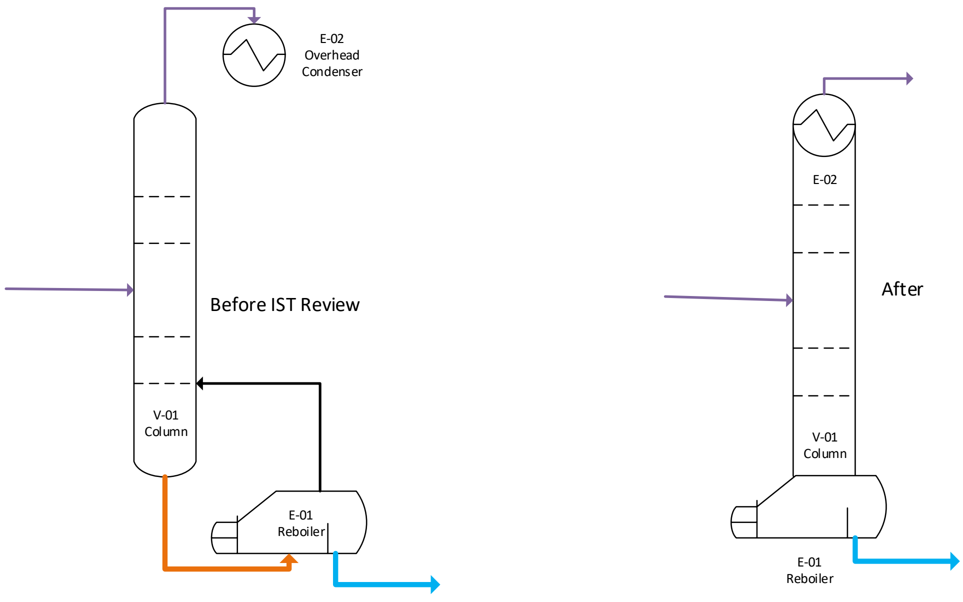

Figure 1. Reducing a Hazard by Eliminating a Pipe During Process Design (FEL2)

Applying IST during the Conceptual Design Phase (R&D Discovery & Development)

Given the success of the IST efforts during design, we expanded further "upstream" to the Research and Development phases of product/process design. We held a half-day IST training seminar for our R&D staff, and did some coaching and ran our IST "what if" review on several process option designs. These early results were promising.

Later an IST workshop was conducted at our Research and Development Center where twenty (20) R&D chemists and engineers attended the event. Three projects were reviewed at the workshop to identify IST opportunities with the use of the original IST checklists from our existing procedure. Feedback from the R&D Directors was positive that the workshop made the attendees become more aware and able to apply the IST strategies on their projects to reduce risk. It was also realized that IST analysis by a team is not just a meeting or a review session – it is actually a way of thinking, a way of approaching technology design at every level of detail which is part of the daily thought process of a chemist, engineer, or designer as he/she goes about doing the work. R&D Chemists and Engineers liked the idea that they should be talking about this as early as at discovery and development stage and not just when projects get to the pilot plant when it may be too late to easily change things. The workshop identified that a more focused IST checklist tool should be developed for the Discovery phase with a separate checklist tool for the Process Technology phase. Development of these checklists had been completed. For the Discovery phase, the Substitute/Eliminate and Moderate strategies would be evaluated. This eliminates the extra checklist which would be of less or no relevance in "Discovery". For the Process Technology phase, all four (4) strategies including siting/location/transportation considerations would be evaluated.

In R&D, to define the basis for the design and construction of commercial scale manufacturing facilities, a Definition of Technology (DOT) Package would be prepared. This applies to new or pioneering technology projects. The DOT package includes a section on Health, Safety and Environmental (HSE) where among other HSE concerns, the IST review results would be documented including a summary table addressing the recommendations. The IST checklists just developed would meet the purpose for DOT.

As in other companies, R&D recommends practical materials of construction as part of the DOT. They are motivated to identify lower cost materials when they can. In one example, R&D looked for – and found – a reaction catalyst that had the same yield at a considerably lower temperature. The lower temperature allowed the use of less exotic metallurgy and a reduced wall thickness, saving considerably on the vessel cost.

During FEL-1 hazard reviews of the projects, we look for IST opportunities using the IST checklist for Process Technology as a memory jogger for possible IST solutions. If there are changes in the scope in FEL-2, the hazard/IST reviews are updated. We count the number of IST "safeguards" vs other follow-up recommendations. The IST recommendations are identified in the Process Safety Goal Result Counts as reported to leadership.

Face-to-Face workshop for Twenty R&D Chemist and Engineers

In preparation for the workshop the Discovery and the Process Technology teams selected three active projects and answered the questions outlined in the first IST checklist draft. During the workshop, participants and facilitators reviewed the answers as well as the types & purpose of the questions and functionality of the checklist. That exercise was very useful. It helped attendees not only understand and assimilate the IST concepts in a setting involving practical cases but also make valuable suggestions on tools and process workflow improvements. It became evident that IST questions needed to be answered in a particular sequence in order to gain effective impact on the maximum safety improvement targeted through the IST methodology. The Discovery team focuses on conceptual chemistries followed by relatively short duration & simplified experimental proof-of-concepts. Chemistry candidates that pass basic hurdles such as economics, raw materials availability, are transferred over to the Process Technology organization. The latter attempts to duplicate the experimental results at larger scale, over long durations and often with recycle of unconverted raw materials. During that process development stage, R&D cost increases dramatically. To maximize return on R&D investment and minimize time-to-market, it is essential that the "substitution & moderation" questions be addressed in the Discovery phase. As a result, the original IST checklist was modified to highlight the key areas that need to be answered by the Discovery and Process Technology teams respectively.

So, here's how our process works today:

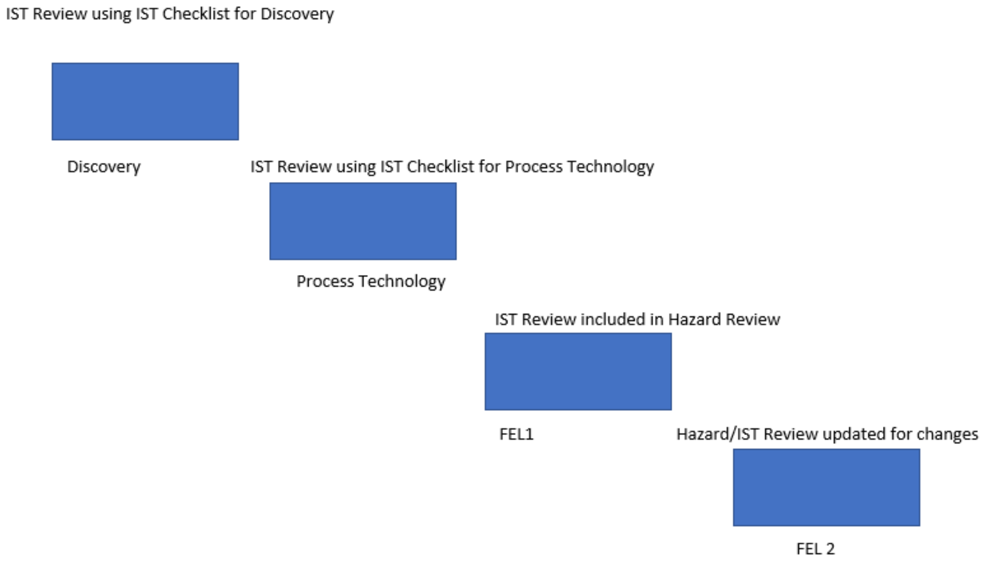

Figure 2 The Phases of a New Product/Process and IST

Although splitting the IST checklist between Discovery and Process Development encourages the division of labor concept, it's important to state that it's applied only early in the IST process. Chemical process development is an iterative process that requires frequent collaborative sessions whereby IST topics are discussed and refined. The Process Engineering team is part of the chemical process development integrated framework. That team focuses on designing commercial scale plants that embody the best equipment operability, safest unit operations and most favorable economics. They provide useful insights on process risk that are considered in the execution of experimental trials by the Process Technology team to **moderate** hazardous process conditions and **minimize** quantities of hazardous chemicals.

Connection to "Definition of Technology (DOT)" package requirements

The Definition of Technology (DOT), also called process technology package by different chemical companies, is the foundational document that encompasses the body of experimental work that supports the design of a new commercial plant. It contains fundamental chemistry and engineering principles that enable decision-making for the selection of raw material suppliers, equipment, materials of construction, process conditions in each unit operation along with consequences of deviations, and most importantly outlines the basis and iterative approaches that lead to sustainable and inherently safer manufacturing processes.

Lessons

Much has been written about IST over the past 40 years. Here are some selected lessons from our experience. Most are self-explanatory. In a few cases, we have elaborated, so the meaning is clear. Every one of these should be read with the phrase "when practical" added:

Some lessons we learned from the R&D Phases:

- When selecting chemistries early on, endothermic reactions are preferable. To elaborate, endothermic reactions are favored when feasible. If not, there are ways to manage exothermic reaction safety as described below.
- A preference for continuous, vapor-phase operation for exothermic reactions.

  Honeywell practices numerous commercial scale catalytic and non-catalytic vapor-phase processes. Vapor-phase processes lend themselves very well to continuous operation. Unlike batch operation, a continuous operation has an inherent safety advantage with regard to smaller reactor size, smaller quantities of materials at any given time, and the ability to stop the reactor feed as soon as process condition are trending off limit. This is especially useful for exothermic reactions as the heat generation can be controlled effectively.
- A bias against the potential accumulation of reactants
- Reduction of inventories, especially of intermediates

  As much as feasible, integrated continuous processes are favored. Those processes may consist of several steps in which each intermediate produced is used as a feedstock for the next process step. Unlike batch reactions that require large inventories of raw materials and of intermediates to maximize rates and yields, continuous processes can be designed with relatively small intermediate storage tanks, or none at all. Where once it was common to provide a tank between each unit operation, improvements in process control have all but eliminated that need. Likewise, improvements in advanced process control offer the possibility of greatly reducing storage volumes between process systems and units without sacrificing rates and yields.
- Moderating temperatures and pressures

  Minimization of temperature and pressure in any given unit operation does not only increase safety but also touches on other important aspect of scaling up a new chemical technology. The selection of materials of construction and process instrumentation depends on operating temperature. Corrosion typically increases as a function of temperature and therefore often reduces the choices of suitable materials. The selection of process instrumentation may also become limited and/or more expensive as a function of high temperatures and pressures. Consequently, there are strong benefits overall to identify a chemistry that can be practiced at low / moderate temperatures / pressures and yet deliver acceptable material selectivity and conversion. In a recent process development project, Discovery's proof-of-concept operating conditions favored a high temperature process. Process Technology was able to change process conditions and achieve a 60% temperature reduction without compromising the reaction yield. Of course this also helps reduce pressure and "flashing liquids" flow in case there ever is a leak
- Ensuring the right metallurgy for equipment & piping handling corrosives (with a combination of literature search and lab-scale testing).
- Avoiding the use of flammable solvents/solutions where possible
- Manage combustible dust hazards by using granular materials or even liquid additives rather than powders

Some lessons from the Equipment Design phase:

- Consider separating loading, unloading & storage facilities for incompatible materials
- Consider mag-drive or canned pumps to eliminate mechanical seals in special situations

  Seals on pumps are a known potential leak points. Over many decades, the process industries have evolved from packing-glands to single mechanical seals. And, when the properties of the fluid being pumped required it, to double-mechanical seals with a buffer fluid and an alarm system to let operators know when one of the seals is beginning to leak. It's also possible – in some circumstances – to eliminate the seal altogether by moving to either a "canned motor" pump or a magnetic drive. The trade-off here is that these pump-drives are limited in their size and capability, so are not suitable for every situation. However, they are a good tool to have in the toolkit and we use them when it makes sense.
- Minimize pipe length and the number of flanges for hazardous materials

- Through-vessel-wall leaks are not unheard-of, but they are quite rare by comparison with through-wall-leaks from pipes, and flange leaks (or leaks from other "mechanical joints" are even more likely.
- Use of nitrogen to transfer a hazardous material from storage containers to holding tanks, as opposed to a pump. Note that such cases should be looked at carefully as sometimes a pump - which can be shut off - is the safer technology.
- Use of high pressure steam (unless the content may react violently with water) or hot salt instead of heat transfer oil for reactor heating/cooling.
- Eliminate utility connections if the utility can run above the pressure rating of vessels.
- In one of our earliest applications of IST – even before Kletz coined the phrase - an entire distillation train is gravity-fed to avoid the use of a pump

One very specific lesson was about the need to document IST "safeguard features" within our Hazard Review

We learned to document IST "safeguard features" within our Hazard Review process so they can be identified and will not be forgotten over the years. Here's an example of why this matters. About 20 years ago, Honeywell (AlliedSignal Chemicals at the time) built a new polymerization batch reactor. As with most polymerization reactions, it was exothermic. And as with most exothermic reactions it had a potential to run away if unreacted material accumulated and then the reaction started. To reduce this possibility, the reactor was designed to run in "semi-batch" mode which is inherently safer, and it was designed with small "shot pot" feed vessels that had been calculated to only have enough material in them to reach a specific temperature/pressure regime that was within the MAWP (Maximum Allowable Working Pressure) of the vessel even if a runaway were to occur. Because of this inherent design feature, an "active" safeguard like a high (or low) temperature interlock was not needed. It took a little more effort by the operator to refill the small shot-pot, but this system worked well for many years.

Many years later, the site was looking for a way to save on manpower and handling costs. They looked at automating the reactor feed system to enable automatic feed directly from the reaction feed vessels, avoiding the shot-pots. No one remembered why they were there. The reasons were not explained in the Process Description, nor on the P&IDs nor in the HAZOP. Fortunately, this project went through an IST review in the early phases and the team figured out that the shot-pot was an inherently safer design feature.

Encouraging the use of Inherently Safer design

We've also learned some lessons about how to encourage the use of Inherently Safer design in our thinking, making it more sustainable.

- Start the LOPA, (Layer of Protection Analysis) as early as possible for selected scenarios
- Document this in the Process Package
- Engage the R&D folks in this so they learn
- The full IST checklist may be overkill for small, MOC (Management of Change) type projects. Consider a more open, What If format for these.
- Learning is cumulative: the more people practiced IST the more it became part of their normal way of thinking.

Conclusions

Using IST can reduce the need for and the cost of active safeguards. The most practical & impactful time to include IST is during the development of new capital projects. The greatest leverage to apply IST is early in Discovery & Development, followed by FEL-1/2 during the engineering phase for commercial plants. Setting goals for conducting IST assessments at the appropriate stages helps sustain the program. In 2019, more than 100 IST considerations were identified for about 20 projects. The effort invested to implement IST was not heavy – mainly training on what IST is and how to use the checklists – perhaps as much as 50 man-days. It's a little hard to quantify, but – in addition to the clear safety improvements - we are confident we have paid this investment back more than ten times over.

References

1. Trevor A. Kletz, Paul Amyotte: Process Plants: A Handbook for Inherently Safer Design, Second Edition Second (2nd) Edition

Glossary:

IST – Inherently Safer Technology

DOT – Definition of Technology. A package of information that is the basis for the design and construction of commercial scale manufacturing facilities.

FEL – Front End Loading. A gated process for Business (FEL-1), Scope (FEL-2), and Project (FEL-3) planning. The FEL process provides approval for business objectives, scope, cost, schedule, and risk at each FEL gate. The FEL phases are the planning phases of a capital project.

New Technology – Process chemistry and/or mechanical technology not previously employed on a commercial scale for one or more processing steps.

Pioneer Technology – Process chemistry and/or mechanical technology not previously employed in a commercial sized plant.