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Are biases towards the recent past causing us to unintentionally expose personnel to increased levels of risk?

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Abstract

This paper focuses on the consideration of an unbiased approach to assessing risk to push the industry towards proactively addressing risk rather than reactively allowing cognitive biases to drive process safety culture and personnel risk management solutions. Scientifically proven to affect the way we process and interpret the world around us, cognitive biases allow us to shortcut the complexities of the world when making decisions. In some cases, biases can be surprisingly accurate, while in other instances they can lead to making poor judgements and decisions based on the limited information available to us. Specifically damaging in the process safety industry are the *availability heuristic* and the *confirmation bias*, which together cause us to focus on information that comes to mind quickly, justifies our opinions, and favors our existing beliefs.

With recent industrial accidents that have resulted in fatalities and a push toward regulatory change in response to explosion events, we have seen a rise in the availability of blast resistant structures such as BRMs and hardened stick-built buildings to protect onsite personnel from explosions. The availability of such blast hardened structures has produced an unfortunate trend of moving personnel back in closer to processing areas. Recent advancements in full-scale testing and computer modeling capabilities suggests that even though such buildings may protect for some level of blast hazards, this approach may result in increased levels of personnel risk from other hazard types, specifically impinged jet fires and toxic exposure. This raises the question: are employees being placed in risky locations in a BRM or hardened building with a false sense of security?

Keywords: Managing Process Safety, Learning from Incidents, Safety Culture, Flammability, Thermal Radiation, Explosions, Toxics, Cogitative Bias, Blast Resistant, Risk, Process Safety, Facilities, Personnel Protection, Safe Refuge Location

Introduction

On March 23, 2005, a vapor cloud explosion (VCE) at the BP Texas City refinery initiated the momentum behind a shift in the fundamental way in which the petrochemical industry views facility siting of temporary and permanent occupied structures (see **Figure 1** for a view of facility damage). In this tragedy, 15 workers were killed and nearly 200 were injured as a result of an ignited vapor cloud that formed from a release of flammable liquid hydrocarbons. (Safety+Health: The Official magazine of the NSC Congress & Expo, 2015) While numerous lessons were learned from this incident and many recommendations were made, arguably the most influential lesson learned was regarding the location of temporary trailers, commonly used for construction and turnaround events, to potential blast events.

Figure 1. BP Texas City, Chemical Safety Board

The BP Texas City incident was not the first VCE to have a significant impact that subsequently influenced industry regulations. In 1974, 28 deaths resulted from a cyclohexane explosion that damaged 1,821 homes and 167 commercial buildings. Approximately 10 years later, the Center for Chemical Process Safety (CCPS) was established. In 1989, a VCE with an initial blast registering 3.5 on the Richter scale caused 24 deaths at the Phillips Petroleum Houston Chemical Complex in Pasadena, Texas. The event led to the establishment of the Mary K. O'Conner Process Safety Center (MKOPSC) and subsequent creation of OSHA Process Safety Management (PSM) in 1992. Shortly after the BP Texas City incident, a VCE in Buncefield, England, was heard up to 125 miles away. (Fitzgerald, Accessed August 2019) These events, which have created a lasting impression on the petrochemical industry, are easily recalled by industry professionals due to their influential nature. As a result of the ease at which these events can be called to mind, there is a tendency for process safety individuals to focus on blast (specifically VCE) as the main hazard of concern for facility siting activities.

This paper explores the impact of the BP Texas City VCE on industry regulations within the US and the subsequent trends with respect to facility siting due to individual biases. The example case study presented is based on the author's experience in performing both consequence and risk-based facility siting studies and is intended to promote discussion around balanced hazard protection. That is, this paper is intended to promote protection for blast, thermal, toxic, and other applicable hazards by removing individuals' natural tendencies towards cognitive biases.

The Interplay of Cognitive Biases with Process Safety

While powerful, the human brain is subject to limitations in processing and interpreting information in the world around us. Cognitive biases, which help us make sense of the input we are receiving and to reach decisions with relative speed, are the brain's attempt to simplify information processing. As such, while we as individuals believe we are being objective, logical, and capable of evaluating all available information, we are constantly taking mental shortcuts (known as heuristics) that creep in and influence the way we see and think about the world. (Cherry, 2019)

It is easy to see how cognitive biases can influence perceptions in all areas of life. This even includes the area of petrochemical process safety, where attempts are made to overcome individual cognitive biases whether we are consciously aware of this or not. Examples include team Process Hazard Analyses (PHAs) with external facilitators, leveraged knowledge shares and lessons learned reviews, and development of accident databases and incident summaries. Regardless, history is lost with time and only the most recent or most impactful events are remembered. To put it as succinctly as George Bernard Shaw, "most new discoveries are made regularly – every fifteen years!" (Maitland, 2015)

We encourage readers of this paper to investigate their cognitive biases and how those biases play a role in daily decision making in our roles. This paper incorporates concepts relating to *confirmation bias* and the *availability heuristic* with respect to historical accidents and facility siting. Confirmation bias is more straightforward of the two and states simply that an individual favors information that supports existing beliefs while discounting evidence that does not conform to that approach. Confirmation bias suggests that an individual actively seeks evidence that supports existing beliefs, which prevents looking at situations objectively. (Cherry, 2019) The authors anticipates that we can all remember a situation where a team member has stated, "that event isn't credible, it has never happened here" or "we've never tested them, but our shelter in place buildings are leak tight" or "the gas cloud will ignite before it gets that large".

The availability heuristic places greater value on information that comes to mind quickly – greater credence is given to this information and as a result, probability and likelihood of similar things happening in the future is overestimated. (Psychology Resource and Reference, 2019) With a recent historical focus on industry VCE events resulting in heavy asset damage, long downtimes, loss of life, and regulatory change, the tendency of petrochemical professionals is to focus on blast events and downplay potential fire and toxic events when discussing facility siting and personnel protection. The availability heuristic leads individuals as well as teams to believe that VCEs are likely to be large and destructive whereas fire and toxic releases are perceived to be smaller and easily isolated with limited personnel impact.

Even with the reference to the Bhopal, India methylisocyanate (MIC) gas leak in the preamble to the PSM standard, toxic hazards continue to be minimized due to the limited number of recent events. This 1984 event led to the death of approximately 5,200 people and permanent or partial disabilities in several thousand more individuals, yet it is mentioned most typically in passing, with a feeling that "something similar wouldn't happen today". (Union Carbide Corporation, 2018) However, some operating companies are recognizing these hazards and proactively replacing toxic chemicals where possible to remove the hazard (e.g., replacement of chlorine for water treatment) as well as establishing mitigation and secondary containment systems with a last resort to provide robust toxic shelter and evacuation programs to protect their personnel. Unfortunately, this is still the exception and not the norm.

With just a few examples, one can see how *confirmation bias* and the *availability heuristic* can greatly influence thoughts on process safety, specifically facility siting. As Trevor Kletz has famously said, "Organizations have no memory…" and "Don't bother to write an accident report, I'll send you one from my files!". (Maitland, 2015)

Impacts of BP Texas City on Facility Siting

Before the VCE incident, the BP Texas City refinery had conducted a site-wide siting analysis in 1995 and again in 2002 to establish layouts for trailers and other temporary structures. With the 5-year PSM refresh cycle in place, an update was due to take place in 2007, except for any changes to siting falling under the management of change (MOC) process. In late 2004, plans were made to place contractors in 9 single trailers and 1 double-wide trailer adjacent to the ISOM unit beginning in 2005; however, an analysis to determine risk for this proposed plan to locate the trailers in accordance with American Petroleum Institute Recommended Practice (API RP) 752, "Management of Hazards Associated with Location of Process Plant Buildings" hadn't been completed at the time of the incident. (Wikipedia, 2019)

After the 2005 BP Texas City incident, The U.S. Chemical Safety and Hazard Investigation Board (CSB) issued an urgent recommendation acknowledging that while BP was compliant with API 752 because the trailers were temporary structures, the CSB recommended that API either update API 752 or issue a new Recommended Practice to ensure the safe placement of occupied trailers and similar temporary structures away from hazardous areas of plant processes. In June 2007, API RP 753, "Management of Hazards Associated with Location of Process Plant Portable Buildings", was published. (U.S. Chemical Safety and Hazard Investigation Board, 2007) In addition, a 3rd Edition of API 752 was released in 2009 to address the Texas City incident, OSHA comments, and NEP findings.

The revised API RP 752 and new API RP 753 included several changes that would impact industry's approach to facility siting, most notably language that transforms facility siting into an ongoing process as well as changing the occupancy basis from a 'man hours per year" calculation to an “intended for occupancy” approach. (Baker, 2011) Both API RP 752 & 753, however, were written to provide companies flexibility in how to assess personnel protection depending on a consequence (simple or detailed) or risk approach as well as allowing for company definition of maximum credible event (MCE). Furthermore, while language was added specifying that thermal and toxic risk should be reviewed as part of facility siting, very little guidance was provided on how to do so; while language was added to require quantitative evaluation of explosion hazards, qualitative or spacing table approaches could continue to be used for thermal and toxic hazards.

The release of these two API RPs resulted in two initial major impacts on facility siting for the petrochemical industry. The first major shift is captured in API RP 753’s guiding principles: “locate personnel away from covered process areas consistent with safe and effective operations”. This is reflective of the trend to move occupied structures from close by the process units to a distance at which personnel would be protected, particularly from blast events. The second major shift was in the rationale behind “maximum credible event” (MCE): companies were no longer allowed to use so called “credible” high frequency smaller release events (flange leaks and plug failures) but instead needed to consider larger loss of containment events associated with pipe and full connection failures. (American Petroleum Institute, 2009) and (American Petroleum Institute, 2007) Along with a shift towards inclusion of larger events for facility siting modeling came a shift from consequence-based siting to risk-based siting, which brought in the element of frequency in addition to the consequence of identified events.

The Rise of the BRM

With the release of the revised API RP 752 and new API RP 753, traditionally constructed permanent buildings (e.g., masonry, unreinforced concrete, pre-engineered, etc. buildings) as well as temporary structures (e.g., modular buildings and wood trailers) were being pushed farther away from process units. Furthermore, due to site real estate restrictions, often consequence results were indicating that weaker structures may even need to be located offsite. While in some situations this had minor impact on site operations, in many cases distance creates a challenge for turnaround/construction crews as well as essential site operations and maintenance personnel. A demand for a solution that would achieve a higher level of personnel protection without having to locate personnel in logistically challenging locations was created in the marketplace.

Blast Resistant Modules (BRMs) entered the marketplace, slowly at first and then in high volume, to fill this demand. BRMs, typically of modular steel construction, are designed to American Society of Civil Engineers (ASCE) building design codes for low (localized damage), medium (widespread damage), or high (loss of structural integrity) response. Depending on the rating of the BRM and the manufacturer, BRMs are designed for a range of maximum pressure loads for a given duration, with the most common BRMs rated as 3, 5, and 8 psi structures with varying impulse sensitivity depending on design/construction. Most purchasers of BRM’s and the BRM vendors focused on the overpressure rating of the BRM structure and used that rating to place it outside of the overpressure zone.

With the rise of the steel BRM, facilities had a product to meet the growing demands for blast protection within the petrochemical industry. BRMs, which can be temporary or permanent in nature, began showing up on sites across the US as well as internationally. With the ability to rent, lease, or purchase these structures, site owners began moving facility personnel closer to processing units using traditional blast contours as guides for siting. However, it is important to understand the vulnerability associated with the structure for a given load (impulse as well as pressure) and not just the response rating – a fact that is often missed by most, resulting in a false sense of protection from blast hazards. Therefore, while utilizing these structures may be compliant with the letter of API RP 752 and 753, BRMs may not meet the intent of protecting the occupants of these structures. But the petrochemical industry tends to be reactive, not proactive, when it comes to safety, and biases had created an unintended focus on the structural survivability of the heavily influential VCE events discussed above.

While the structure of an empty metal BRM may be rated for blast events, BRMs typically provide little thermal or toxic protection for sites with other hazards of concern without additional costly design considerations. Typically, standard BRMs are metal paneled structures which may have windows and standard air handling units and may have less thermal and toxic protection than a traditional plant stick-built structure. However, with preliminary design considerations such as intumescent coatings (thermal), elevated air intake and HVAC shutdown systems (toxic), and removal of windows / installation of protective seals (thermal and toxic), BRMs may be able to provide improved protection required for personnel located near operating units. As a market product, these additional protective features are not standard offerings with BRMs and result in an increased cost per square foot, introduction of secondary hazards resulting in unsafe internal environments, additional complexity in retrofit requirements, and increased maintenance costs.

A Case Study for Balanced Hazard Protection

As a result of a bias towards siting for VCEs, blast resistant structural design and implementation has matured into a reasonably well understood field. In comparison, toxic and thermal performance is lagging due to the lack of emphasis on these hazards, with solutions intended to address these hazards applied, but at a lower level of rigor.

The following case study highlights the concepts described above. This case study focuses on the conceptual consequence and risk associated with locating a trailer, a traditional 3psi long duration / medium response BRM, an enhanced BRM for toxic and thermal protection, and a stick-built building designed for balanced hazard protection for an existing facility.

<u>Building Location</u>

In this case study, the client wants to site a permanent structure (shown in green in **Figure *2***) for contractors and employees to use as an operator shelter and permit writing area. While API 752 and API 753 both allow for either consequence or risk-based siting, this client wants to site based on consequence criteria for personnel protection. The structure will be utilized for contractor and employee offices, change rooms, and restrooms.

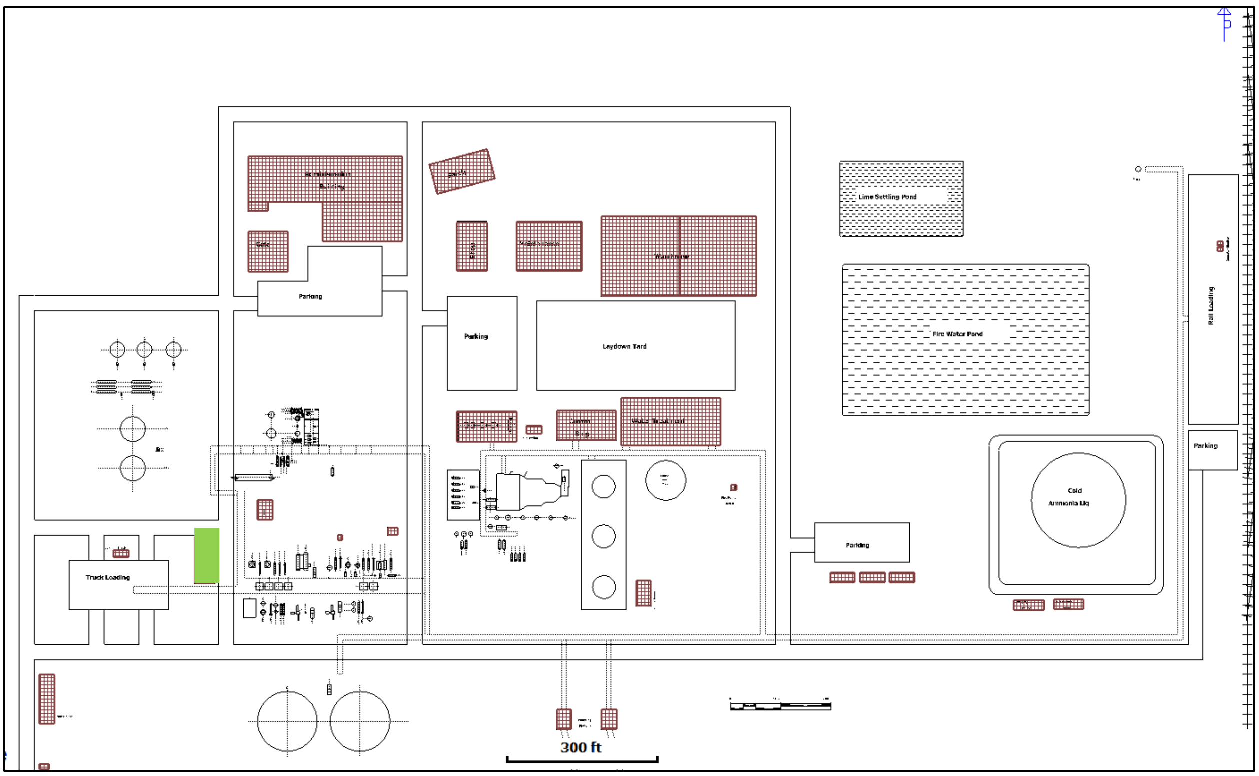

Figure 2. Facility Plant Plot Plan (Building Location Shown in Green)

The client is considering three different building construction types: a traditional wood trailer, a 5psi long duration / medium response BRM, and a stick-built building designed for balanced hazard protection. In addition, they are considering a fourth option as a retrofitted BRM to have additional thermal and toxic protection for personnel. A summary of the building options is shown below in Table 1, with a representation of level of protection by hazard type as well as a representation of relative cost.

Table 1: Building Option Summary

Building Option	Hazard Resistance			Relative Cost	Additional Details
	Blast	*Thermal*	*Toxic*		
Wood Trailer	Low	Low	Low	$	Traditional off-the-shelf trailer.
BRM	Medium	Low	Low	$$	Standard blast resistant building, designed for medium response at 5psi long duration.
Retrofitted BRM	Medium	Medium	Medium	$$$	Windows have been removed and intumescent coating has been applied to BRM. HVAC has automatic shutdown on gas detection and building has elevated air intake.
Stick-Built Concrete	High	High	High	$$$	5spi long duration, low response concrete structure without windows. Doors have been designed with thermal and leak tight seals and the building has interior SIP room with separate, isolatable air handling system and elevated air intake.

Figure *3* shows the overpressure contours (i.e., blast contours) for the facility operations, with pressure thresholds of 0.6, 0.9, 3, 5, and 10 psig. Note that the desired building location falls within the 0.9 psig pressure threshold but outside of the 3psig threshold. Assuming a corresponding long duration event, this location is not suitable for a wood trailer based on blast exposure. In addition, while the BRM is rated up to 5psi, it is designed for medium response indicating that the building may experience significant deformation, potentially resulting in internal debris/projectiles and a subsequent level of increased occupant vulnerability. The custom designed stick-built concrete structure is predicted to receive minor damage at the specified location and is likely immediately available for occupancy post event. *Note that for simplicity, the author is not addressing the importance of impulse in this paper; however, when designing for overpressure, governing loads along the pressure-impulse curve need to be addressed.*

Based on the specifications of the API Recommended Practices, the wood trailer, whether intended to be permanent or temporary, is unacceptable at this location following the detailed analysis approach based on predicted blast overpressures, while the BRM and stick-built structures in

Table 1 would meet the blast requirements specified by API 752/753.

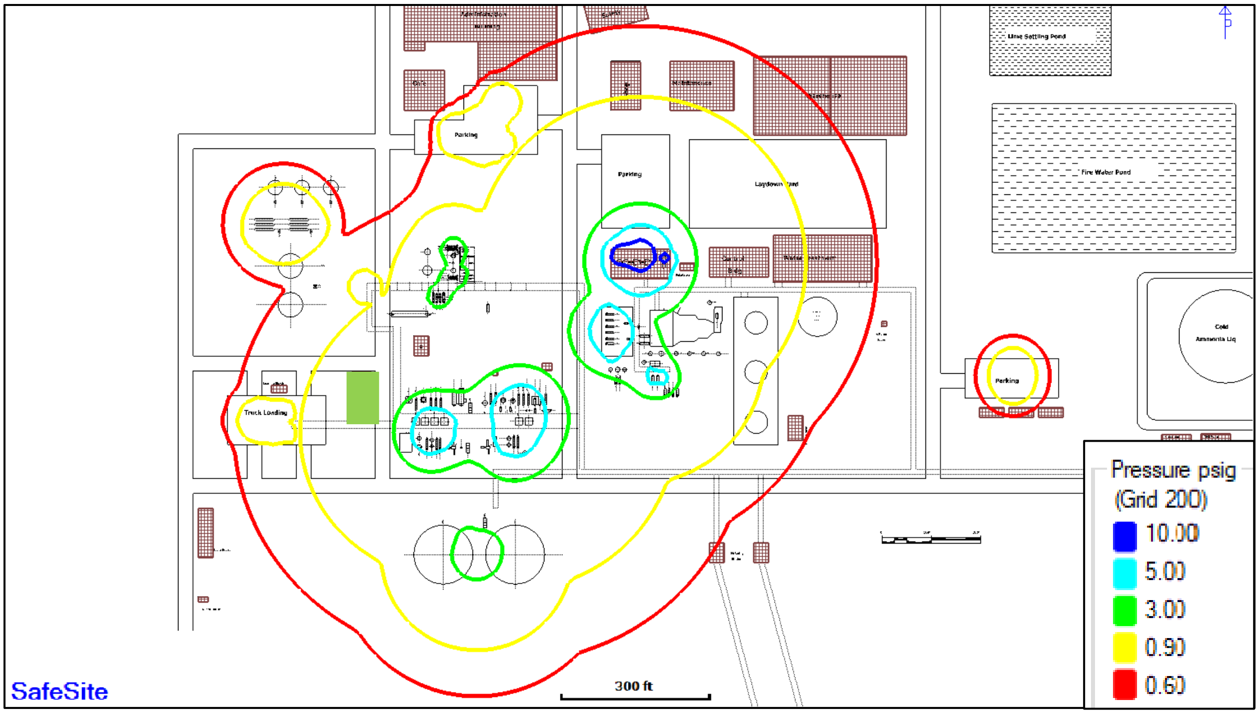

Figure 3. Blast Contours for Facility

It is not uncommon when locating buildings for contractors and temporary employees to use available consequence contours, which most typically are retained onsite as blast contours. For sites employing this process and locating buildings based on blast contours alone without undertaking a robust facility siting MOC process, an off-the-shelf 5-psig BRM would appear to be a satisfactory, cost-effective option for personnel protection. The decision to use a BRM would be reinforced by the *availability heuristic* and *confirmation bias* in two ways: the typically held belief that explosions are the most likely hazard and maximum credible event for personnel exposure as well as the idea that personnel are protected by a Blast Resistant structure. In fact, how often have we all heard these structures mistakenly called "Blast Proof", thus reinforcing biases?

On the other hand, a site following the full intent of the API Recommended Practices and treating facility siting as a living analysis that covers a full range of potential hazard types (explosion, thermal, and toxic) would want to review the vulnerability of personnel in the BRM from blasts as well as the thermal and toxic exposures of additional potential MCEs.

Figure *4* shows that the desired building location falls within the >37.5 kW/m^2 thermal radiation threshold, which is the point at which steel begins to lose its mechanical strength. This is well above the 12.5 kW/m^2 threshold for piloted ignition of wood, further ruling out the usage of an off-the-shelf wood trailer in this location. In addition, a prolonged thermal exposure of this magnitude would not only significantly impact the structural integrity of a standard steel BRM, but also result in significant heat rise within the structure. This leaves two potential options for consideration: a retrofitted BRM with thermally sealed doors, intumescent coating, and no windows, or a stick-built concrete structure with thermally resistant seals and no windows.

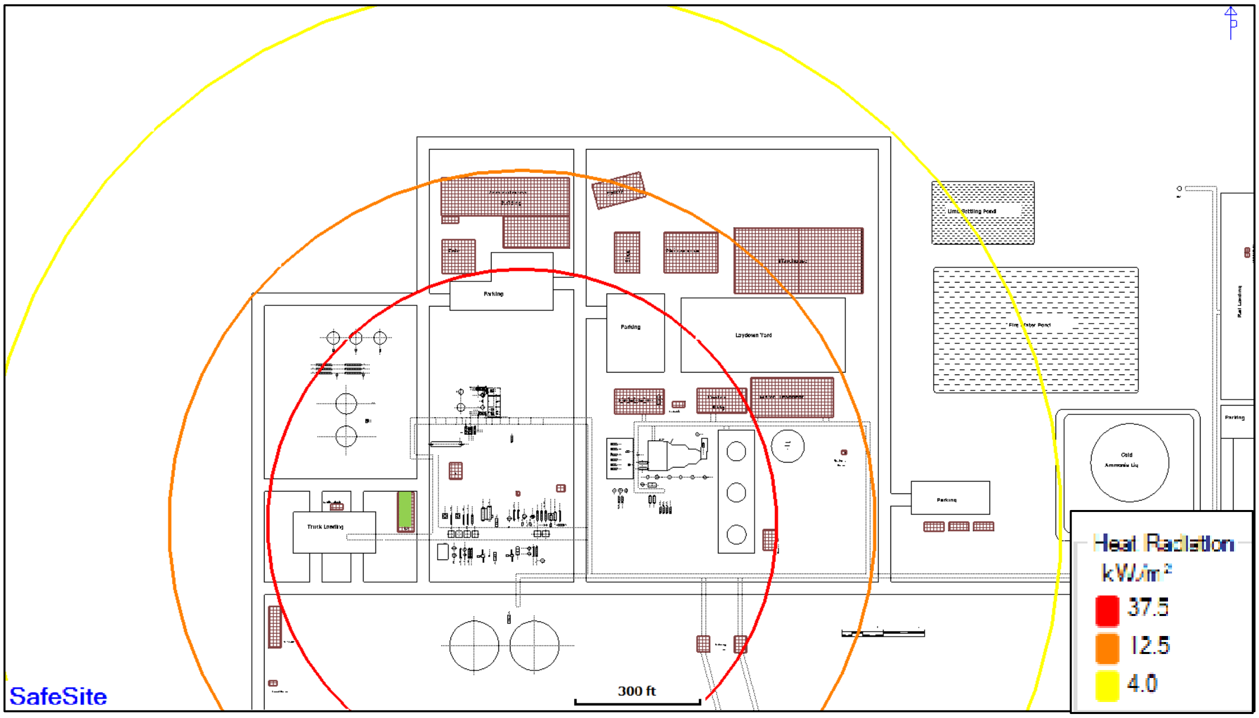

Figure 4. Thermal Contours for Facility

Overcoming biases that may lead one to think that VCE is the maximum potential exposure for an exposed population has led the client, in this example, away from the choice of an off-the-shelf BRM and towards a safer solution for building occupants. At this point, cognitive biases could again rise to the forefront: *confirmation bias* may lead a facility team to determine that a structure designed to prevent heat rise with thermal seals and no windows is certainly good for toxic protection and the *availability heuristic* may lead to a belief that a toxic event resulting in death is rare and may be considered non-credible. The definition of credible is nebulous, at best, and this belief may be justified by the language in the API Recommended Practices. Regardless, due diligence should lead the facility internal or external consequence modeler to also review potential acute toxic hazards.

Figure 5 shows the site toxic consequence profile, which indicates that the desired building location is within the 90% lethality threshold for 10-minute toxic exposure (low pressure chlorine release). From a consequence standpoint, personnel housed in this building for a release duration for 10-minutes or longer would need a significant level of toxic protection. This again rules out the wood trailer and standard BRM options. In addition, while a BRM can be retrofitted with a robust HVAC shutdown system upon gas detection and air tightness can be greatly improved, it is unlikely a standard BRM can be improved enough to provide long duration exposure without supplied breathing air or escape protection. Any building intended to serve as a toxic shelter also needs to be maintained as one. Door gaskets and active protection like HVAC shutdown, alarms, etc. need to be maintained and tested as safety critical systems to ensure the performance on demand. Air tightness cannot be presumed, and structures should be tested regularly to ensure they provide the necessary protection.

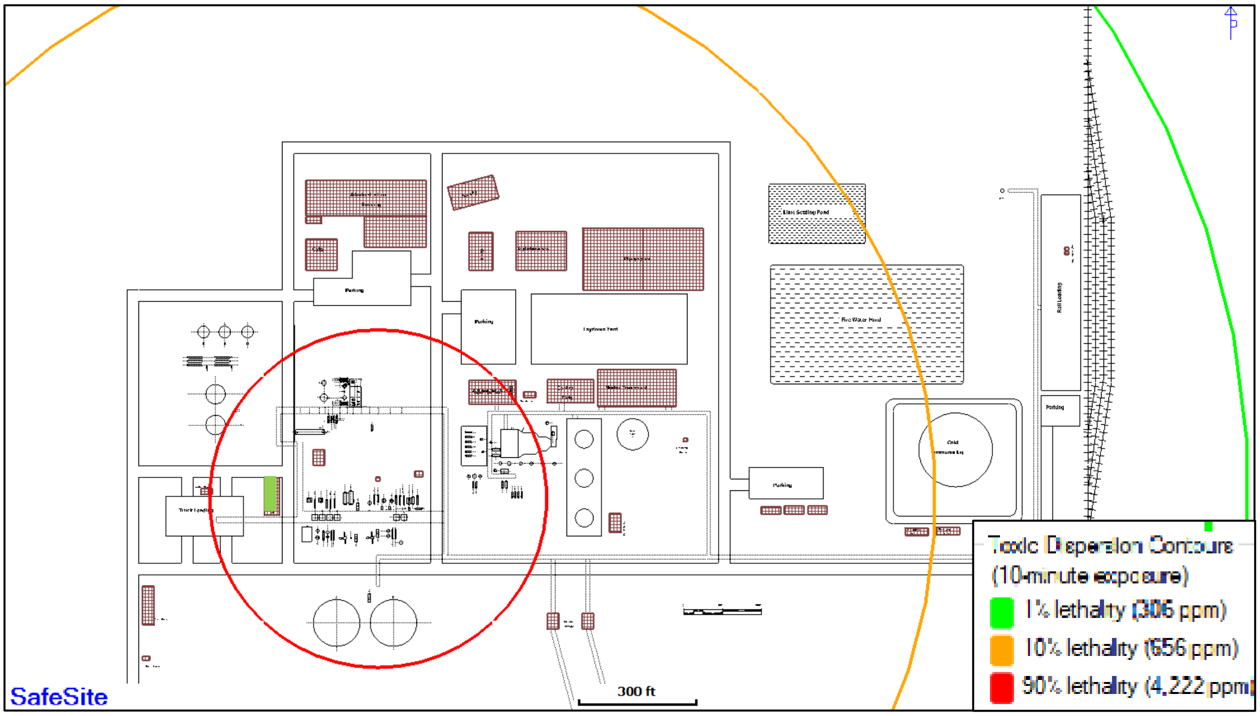

Figure 5. Toxic Contours for Facility

An air-tight, purpose-built structure described in the concrete option may be constructed such that it can provide highly effective personnel protection. While no structure can claim to be 100% effective against toxic gas ingress, a combination of the following can significantly reduce the likely impact to personnel:

- Building should be leak tight, with robust seals around potential leak points and no windows. Leak points should also be minimized, with limited wall and roof penetrations.
- A vestibule to help minimize air exchange with the outside and personnel enter and leave the structure.
- Designated interior SIP location (i.e., conference room or similar designated space) with separate air handling unit and sealed penetrations to main building volume. The air handling unit should condition the air for occupant comfort, but not have any fresh air make up.

- Automatic shutdown on air intake as well as a manual shutdown back-up. The system should trip into 100% circulation mode where the air handling system for the SIP is independent of the overall building air system.
- Slight fresh air flow into internal SIP room volume, with supplied air and escape masks for the maximum predicted occupancy.
- Toxic gas detection outside the building as well as inside the building in the door / vestibule area. Additionally, internal room SIP should have gas detection that alerts when that location approaches the predefined uninhabitable threshold, providing occupants time to implement the evacuation plan.
- A robust communication, training, and fall-back plan addressing an integrated emergency response that covers both sheltering and eventual evacuation if the building becomes a lethally toxic environment.

For a purpose-built structure meeting these minimum requirements, a case may be made that both the retrofitted BRM and the stick-built concrete structure are designed for safe occupancy at the given location based on the criteria and requirements of API RP 752/753. However, at this point, the internal or external consequence modeler should consider progressing the analysis to a risk-based facility siting analysis to determine the risk profile for building occupants. There are two reasons for this: first, to bring in the frequency of MCE events as well as the average exposed population, and second, to determine relative risk reduction vs. cost increase for the available structural options.

For this case study example, a hypothetical risk profile comparison for the four options considered is shown in **Figure *6***. From a review of hazards on a consequence basis, the wood trailer and standard BRM do not appear to be viable options for the desired building location. However, both the retrofitted BRM and the stick-built concrete options would meet the corporate risk criteria. With either construction type a viable option, a cost analysis (***Figure 7***) can provide further feedback and guidance on which option to select for construction.

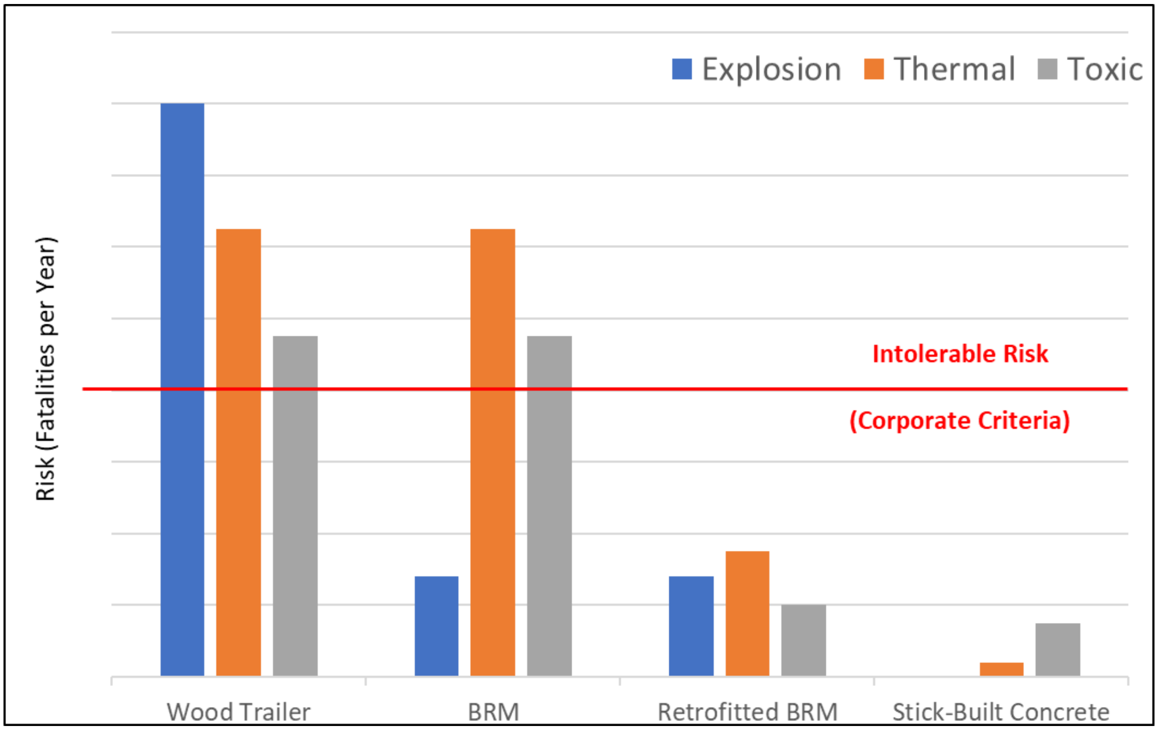

Figure 6. Risk for Each Option Considered

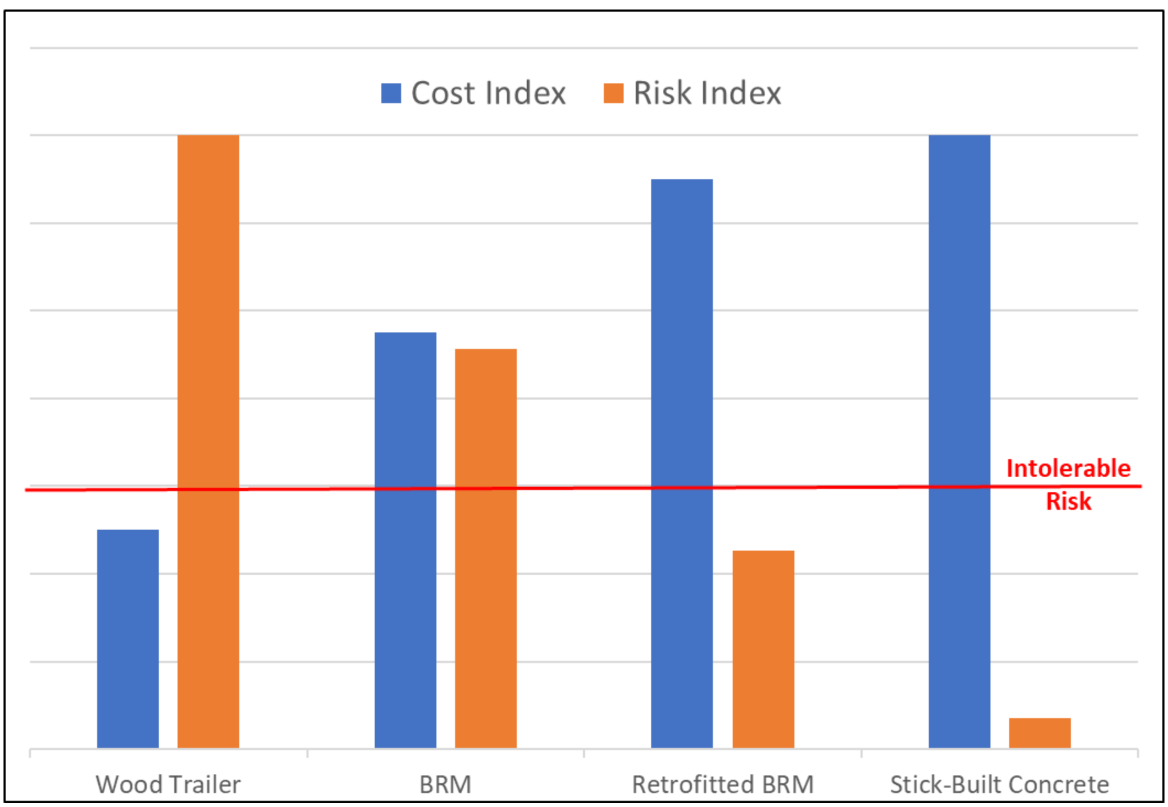

Figure 7. Cost and Risk Indices for Each Option Considered

With either the retrofitted BRM or stick-built concrete structure viable options, it becomes a business decision on which to select. In this example, a minimal increase in cost results in a significant reduction in the overall risk profile. The increased risk protection provides flexibility for future business decisions such as adding hazardous assets (i.e., increasing the frequency of exposure) as well as adding future occupancy. It is important to remember that protection systems require maintenance and upkeep, or they lose the ability to provide protection. It is, therefore, preferable to choose construction types that provide the necessary protection with the lowest level of required maintenance.

Conclusion

Cognitive biases are essential for humans to quickly process the world around us. Through the mental simplification process, both individuals as well as groups often put aside our objective and logical selves in favor of the information that reinforces our beliefs and recent history. Due in part to cognitive biases in combination with the ease at which high impact VCEs can be called to mind, the author proposes that there is a tendency in process safety to focus on blast hazards and occupant exposure when conducting facility siting.

The case study in this paper is an example of the potential consequences of this shortcut in mental calculations, which would have resulted in an increased exposure to thermal and toxic hazards due to the available of a blast resistant structure. To limit the impact of cognitive biases on individuals and teams, care must be taken in the facility siting MOC process to follow a standard procedure designed to limit the effect of mental shortcuts on decision making for safety. Once the full consequence and risk profiles are available, business decisions can be made that balance exposure with cost implications.

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