Received: 29 March 2024 | Revised: 13 May 2025 | Accepted: 29 May 2025
DOI: 10.1002/prs.70001

PROCESS SAFETY PROGRESS

ORIGINAL ARTICLE

Building design requirements for multi-hazard protection

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Abstract

Blast resistant buildings have traditionally been quantified by the ability to resist blast loads for a prescribed level of structural damage. Focus has been placed on the structural performance (i.e., building response) without fully correlating this to occupant vulnerability. Fire and toxic material hazards and their impact on building occupants is often overlooked, resulting in buildings that do not comply with the full intent of API's Recommended Practices 752 and 753 (API RP 752/753). The definition of occupant vulnerability, per API RP 752/753, is the "portion of occupants that could potentially experience a life-threatening injury or fatality if a potential event were to occur." As summarized in the fourth edition of API RP 752, "owners/operators should understand and document the basis for the correlation [between building damage and occupant vulnerability] and assess its applicability."

KEYWORDS

blast analysis, blast resistant building, facility siting, MRB, occupant vulnerability, occupied building siting, protective building

1 | INTRODUCTION

With[1] the release of updates to the API's Recommended Practices 752[2] and 753[3] (API RP 752/753) in January 2024, it is the appropriate time to examine two guiding principles that facility owners and operators should consider for implementing facility siting recommendations for occupied buildings.

The most important guiding principle of the two is "The Golden Rule", which states: *whenever possible, locate your personnel in buildings away from hazardous areas*. However, this is not always possible. Facilities that have been in place for many years may not have the available land to expand beyond their existing footprint. Additionally, many hazardous processes require operators to be located near the units for ease of daily operations and quick response if an incident occurs. The second guiding principle dictates that occupied buildings should be designed to protect workers from hazards associated with the facility, which could include explosion, fire, and toxic material releases. When reviewing facility siting results and implementing recommendations, these two principles should drive decision making.

While this paper focuses on the siting of occupied buildings, it is important to note that it is equally important to protect critical equipment, which is often responsible for mitigating any potential hazardous event or preventing further injury or loss of life by providing a safe environment in which to bring operations under control. In fact, the Chemical Safety Board (CSB) report on the Philadelphia Energy Solutions (PES) incident (see Figure 1) resulted in five recommendations,[4] one of which focused on safeguard reliability in critical buildings[5]:

Update API RP 751 Safe Operation of Hydrofluoric Acid Alkylation Units to require the following:

A. Protection of critical safeguards and associated control system components, including but not limited to wiring and cabling for control systems and primary and backup power supplies, from fire and explosion hazards, including radiant heat and flying projectiles; and
B. Installation of remotely operated emergency isolation valves on the inlet(s) and outlet(s) of all hydrofluoric acid containing vessels, and hydrocarbon containing vessels meeting defined threshold quantities.

This CSB recommendation acknowledges the need for buildings housing critical safeguards and associated control system components to be designed as robust multi-hazard resistant buildings

FIGURE 1 PES fire and explosions, courtesy of WCAU Philadelphia.[6]

(MRBs)—providing protection not only against blast events, but also from fire (radiant heat) and debris hazards. Whether this recommendation is adopted by the API, it is anticipated that industry will focus best practice on robust design for buildings housing critical equipment and controls. Therefore, best practice for facility siting would include addressing these critical buildings in addition to the occupied building situations discussed in this paper.

This paper summarizes the recent changes to API RP 752 and API RP 753 with a focus on building response to blast, fragments, fire, and toxic impacts. A paper previously published in Process Safety Progress (PSP) provides a detailed look at building design and selection.[7] After summarizing hazards with respect to building impacts, this paper walks through a petrochemical facility case study discussion on locating buildings based on demonstrated occupant vulnerability to facility hazards and understanding the information to reduce your onsite risk profile.

2 | PROTECTIVE BUILDINGS

Industrial facilities are potentially vulnerable to hazards such as explosions, projectiles and debris, fires, unignited toxic gas leaks, and extreme weather. Hazards are increased for buildings in or near process units, which are typically where buildings housing essential operations personnel are sited out of necessity and/or convenience. When occupied buildings covered by API RP 752 and API RP 753 must defend against the full range of applicable hazards to ensure the safety of personnel and for conditions where a facility siting study shows exposure to multiple hazards, a MRB should be specified. A MRB is a holistic solution that provides personnel and equipment protection, peace of mind, and additional security even in high-risk environments containing numerous hazards.[8]

Figure 2 shows a FORTRESS Protective Building designed as an MRB Operator Shelter. This building was designed to be an MRB to ensure field operators are protected and can quickly respond during an incident to mitigate the event (first line of response) in an area with high blast, debris, fire, and toxic hazards. For a properly designed MRB, there are two equally important aspects: the design must focus on the vulnerability of the people as much as the response of the building.[8] For more information on this important distinction, see the hazard specific sections below as well as the case study presented.

2.1 | API RP 752 and API RP 753 2024 updates

Updated API RP 752 and API RP 753 recommendations were released on 16th January 2024.[2,3] API Recommended Practices are not a collection of rules but rather a collection of industry's knowledge and experience rooted in sound engineering and operating practices. With the release of updated recommended practices with respect to occupied permanent and portable buildings, API is recognizing the need to adapt to new challenges and emerging technologies as well as

FIGURE 2 A FORTRESS protective building utilized as an MRB for operators.[9]

demonstrating a desire to enhance safety and ensure compliance with the latest industry developments.[9]

While the updates to API RP 752 and API RP 753 do not include substantial changes in the overall approach or definition of what to assess in facility siting, there is additional guidance provided in the form of tables, bulleted lists, and examples as to how to evaluate hazards and risk.[10] One notable change is the emphasis on examining occupant vulnerability versus building response. While building damage can be used as a siting evaluation criteria, API RP 752 recommends that "owner/operators should understand and document the basis for the correlation and assess its applicability". In addition, the guidance on fire and toxic hazards have been enhanced to emphasize these hazards shall be addressed with the same rigor as blast hazards.

2.1.1 | Applicable hazards

In Section 5.2 of API RP 752, the consideration of applicable hazards states: "Owners/operators shall determine if the building intended for occupancy under consideration could be impacted by a credible explosion, flammable vapor release, thermal radiation, or toxic material release." It goes on to state that for each hazard that can impact the building, siting for that hazard shall be conducted per subsequent sections and documented.[2] While the method of assessment can vary from a spacing table approach to a consequence or risk-based approach, reviewing and addressing the full range of hazards, as applicable, is nonnegotiable.

2.1.2 | Occupant vulnerability

As noted above, reviewing the hazard impacts on buildings (i.e., the building response) can no longer be considered best practice when discussing the safety of occupants. The updated recommended practices acknowledge that there are available published methodologies for determining occupant vulnerability based on different construction types and while there is not a requirement for siting to be based on vulnerability when taking a spacing table or consequence-based approach, API RP 752 does state, "…owners/operators should understand and document the basis for the correlation and asses its applicability." Furthermore, a risk-based approach should utilize robust vulnerability models in calculations.

Figure 3 shows the results of a BakerRisk testing program to examine the correlation between building response during an explosion event and internal debris hazards for different construction types.[11] Significant internal debris from an explosion is a better indicator of building occupant vulnerability than building response is. The example in Figure 3 shows a steel Blast Resistant Module (BRM) that experienced a "Low damage rating" (see Section 3 for response references) for the explosion test, and yet the interior nonstructural debris would have resulted in severe injury or worse.

2.1.3 | Risk mitigation

Once an owner/operator understands the building response from applicable hazards as well as the vulnerability, a building mitigation

FIGURE 3 A BRM before and after – vulnerability matters.[11]

TABLE 1 Building damage levels (BDL) for blast analysis and design.[12]

Damage level	Description
Low	Localized component damage. Building can be used; however, repairs are required to restore integrity of structural envelope. Total cost of repairs is moderate
Medium	Widespread component damage. Building should not be occupied until repaired. Total cost of repairs is significant
High	Key components may have lost structural integrity and building collapse due to environmental conditions (i.e., wind, snow, rain) may occur. Total cost of repairs approaches replacement cost of building

plan can be established for existing buildings, or a protective building design specification can be established for new buildings based on the preliminary hazard and/or risk modeling. API RP 752 includes a hierarchy of mitigation measures in Table 1 of Section 5.5.3, which is a very helpful addition that includes ways to reduce risk through process changes, facility mitigations, or building improvements. The most prevalent issues that the authors of this paper see with respect to building design specifications for hazards are a clear definition of blast requirements for building response, with little to no specification for other hazards.

3 | BLAST RESISTANT DESIGN

In addition to API RP 752 and API RP 753, other owner-enforced blast design guidelines often recommend that essential buildings are designed for a low building response (i.e., limited to localized damage such that the building can be reused) for the design-basis blast event(s).[9,12–15] These documents provide analysis methodologies and acceptance criteria (i.e., damage limits) for blast loading, but no specific guidance on fire and toxic design considerations. Specifications and designs for new buildings tend to be focused on blast load requirements in terms of acceptable structural rather than occupant (personnel) vulnerability. The owner/operator should ensure that facility siting takes these analyses one step further to correlate building response to actual personnel impacts.

3.1 | Structural response

Blast design guidance documents define structural damage levels in terms of the peak deflection of a structural component. The deflection levels may be normalized to the deflection at which the component yields (ductility ratio) or the span of the component (support rotation). Most criteria were originally developed by the U.S. Department of Defense for the design of structures to resist accidental explosions.[16] Individual component damage levels are used to develop an overall Building Damage Level (BDL), as defined in Table 1.

While a properly designed structure should protect building occupants from structural failures during a blast, there are other secondary hazards that are often overlooked when addressing building response that should not be overlooked when addressing facility siting. As discussed in a previous paper,[8] nonstructural items necessary for the function of a structure (cabinets, shelves, desks, electrical equipment, ducting, lighting, etc.) can become sources of hazardous debris to building occupants. This is especially true for building construction types where the wall and roof members are designed to deflect, which occurs with such speed that items near or attached to the deflected walls become projectiles. This has been observed in full-scale tests of metal buildings, both standard buildings and those designed to be blast resistant.[11]

Precast concrete buildings have more inertial mass compared to steel buildings, meaning wall and roof members have lower velocities and generate less hazardous debris. This was demonstrated in a shock tube with applied pressures exceeding 20 psi without generating hazardous nonstructural debris.[8] This was further demonstrated when BakerRisk® tested the FORTRESS Defender, a 6-inch precast reinforced concrete building, at their Box Canyon test facility in August of

FIGURE 4 Precast reinforced concrete building test – negligible vulnerability.

2023. Per the ASCE response criteria, the Defender experienced low damage as shown in Figure 4 where hairline cracks are marked on the inside face of the reflected exterior concrete wall. These were only observed by removing the undamaged drywall and were considered superficial (i.e., the structure is reusable). Furthermore, as shown in Figure 4, the post-test results showed no internal debris or occupant vulnerability from the test.

3.2 | Other occupant vulnerability considerations

Another way that nonstructural debris can become an issue is from an unanchored building sliding during a blast event. In the full-scale test program conducted by BakerRisk, an unanchored ISO container was subjected to deflagration blast loads.[11] A 4.9 psig test with a short duration of 22 ms resulted in the ISO container sliding 35 ft. on its concrete foundation. Damage incurred by the ISO container walls and roof after this test is shown in Figure 5, and resulted in a significant amount of internal debris from both local wall and global sliding movements.

Similar test results have been observed on full-scale steel BRMs when tested at approximately half the manufacturer's specified rating. The magnitude of sliding observed in these test programs produces velocities and accelerations that can cause injuries to personnel.[8] These testing programs are representative as to why facility siting decisions should not be made based on building response only.

4 | MULTI-HAZARD RESISTANT DESIGN

As mentioned above, there are several structural focused blast guidelines that document how to analyze blast loads on buildings; however, none of these address fragments, fires, toxics, or extreme weather. API RP 752 and API RP 753 are trying to close this gap with respect to occupied buildings by including information and references for not only how to calculate fire and toxic hazards, but also how to correlate that to occupant vulnerability. With these changes, a building asserting it is API RP 752/753 compliant should be capable of documenting its multi-hazard resistant design; however, it will be the responsibility of the owner/operator implementing facility siting results to confirm building compliance with hazards modeled.

4.1 | Fragments (and extreme weather)

While API RP 752 and API RP 753 do not directly address fragment hazards, fragments are a known hazard on industrial facilities in the form of vessel ruptures, explosion debris, and extreme weather debris. Care should be given by the owner/operator in building construction material selection and building design when they are aware of hazards that may result in high-speed projectiles. This is especially true in locations that are subject to hurricanes and tornados since these events have a higher likelihood in many cases of catastrophic operational hazards. A true MRB will specify projectile ratings and/or have undergone some level of ICC-500 testing for natural hazards.

4.2 | Fire

Industrial fires result in thermal radiation hazards, which shall be considered based on the updated API recommended practices. Fires to be considered include flash fires, jet fires (Figure 6), pool fires, and fireballs; however, it is noted that flash fires and fireballs typically only

FIGURE 5 ISO container after testing.[11]

impact personnel in buildings during evacuation. Several methods are included as examples on analyzing fires, and Table 4 of API RP 752 highlights the primary fire effects on buildings, which include flame impingement; thermal radiation flux or dose; convection thermal flux or dose; pressure; and momentum.[2]

The most impactful change in API RP 752 for fire hazards is where occupant vulnerability is addressed in Section 5, table 5 – which is reproduced below in Table 2. This section highlights that not only are there concerns based on heat flux at the building location, but an owner/operator should also consider specific vulnerability impacts based on the scenario such as time temperature rise in a building and the impacts of smoke and other combustion products on people over time. In addition, details are also provided on how to evaluate a fire refuge building.

The importance of why an owner/operator should consider occupant vulnerability for fire impacts when locating an occupied building is highlighted in Figure 6. Due to their stated building response to blast loads, standard steel BRMs are often located within or very close to processing units. Typical BRMs have low fire resistance and can reach hazardous temperatures within minutes when exposed to a jet fire. The heating of the crimped steel plate and subsequent interior architectural items creates toxic off-gassing at levels lethal to occupants. A ¼-inch saturated propane jet fire applied to a single wall of a BRM demonstrated these shortcomings; within a short duration, the fire destroyed the building interior as shown in Figure 7. The use of intumescent coatings can partially address jet fire hazards, but siting a BRM well away from jet fire hazards is generally required to fully address the hazard.

There are some ways to upgrade existing buildings for fire impacts, which a protective building design consultant can assist with. This may include measures such as installing fire resistant panels around the building, erecting a concrete fire wall, or wrapping the building in concrete panels. For new building construction, fire is best mitigated against by the building construction type – with precast reinforced concrete providing the best thermal mass for fire protection. When implementing the facility siting study in building specifications, an owner/operator should ensure their design specifications request the right building construction for inherent protection.

4.3 | Toxic

In the updated API RP 752 standard, it explicitly states that if a credible toxic material release can impact a building at acute levels such as

FIGURE 6 Jet fire test from BakerRisk's Wilfred E. Baker test facility.

TABLE 2 Building consequences associated with fire type (per API RP 752).

	Hazard	Pool fire	Jet fire	Fireball	Flash fire
Immediate effects to building occupants	Ignition of building envelope	Yes	Yes	Yes	No
	Failure of windows	No*	Yes	Yes	No
	Internal flash fire or VCE	No	No	N/A	Yes
Time-dependent effects to building occupants	Toxic fumes from building component/content degradation	Yes	Yes	No	No
	Temperature rise in building	Yes	Yes	No	No
	Ignition of building envelope/contents	Yes	Yes	No	No
	Structural failure due to thermal weakening	Yes	Yes	No	No
	Ingress of smoke and combustion products	Yes	Yes	No	No
Effects during evacuation to building occupants	Flame contact	Yes	Yes	Yes	Yes
	Thermal radiation/dose	Yes	Yes	Yes	No

ERPG-3, AEGL-3, or equivalent, a siting evaluation for toxic material release is required.[2] Figure 4 of API RP 752 Section 9.1 is a flowchart of the process for evaluating toxic impacts on buildings, which can include analysis using toxic concentration impacts or dose impacts for inside and outside the building (evacuation vs. shelter). Furthermore, Section 9.4 goes on to discuss the differences between a building

FIGURE 7 Interior of steel BRM after external jet fire.

analyzed for evacuation versus sheltering (i.e., toxic refuge). For toxic refuge buildings, owners/operators should specify whether the building is a safe haven or shelter-in-place (SIP) location, and buildings should be designed accordingly. For an example of a toxic refuge, see Figure 8 below.

Details on performance requirements are summarized in Section 9.4.3 of API RP 752. It is important to understand that nonstructural damage to buildings such as window glazing, door gaskets and HVAC connections. may compromise a building's effectiveness as a toxic refuge. A summary of the requirements for accurately determining a building's performance for toxic SIP are as follows.

A. Length of time that the toxic material impedes the refuge.
B. Number of occupants in the refuge.
C. Length of time that the toxic refuge meets the internal environmental quality criteria.
D. Length of time occupants are required to remain in the refuge.
E. Airtightness of the refuge.
F. Length of time for an event to escalate so as to impair the refuge or evacuation.
G. Ability of emergency response to evacuate the refuge if evacuation is needed.

Annex D in API RP 752 is provided as an informative appendix to provide typical building protection features for buildings used as refuges from flammable/toxic material exposure. Most importantly, Annex D includes Table D.1, which differentiates typical protections for safe havens and SIP locations and includes protection features such as facade, doors, and windows; ventilation; envelope tightness; gas detection; response to gas detection; PPE; and maintenance/inspection. One of the most important tools in determining the potential protection provided by your identified safe haven/SIP building is air ingress testing, which determines the rate at which outside air enters the structure. Typically, several configurations are evaluated including (a) before HVAC/isolation occurs, (b) inside the main building volume after HVAC/isolation, and (c) inside an interior room used for sheltering (as applicable). Facility owners/operators should utilize this annex when implementing facility siting study results in new building design specifications.

5 | CASE STUDY

This case study is based on an analysis previously submitted in the 2020 AIChE GCPS paper *Leveraging Process Safety Techniques in Capital Projects*.[17] This paper introduced a stage gate review process to minimize personnel exposure, asset damage, and business interruption while also controlling costs and ensuring ease of project implementation. The implementation of facility siting results is one of the concepts presented in the Capital Projects paper and is worth reviewing in the context of this paper. Through the early application of facility siting, capital projects can improve designs in terms of risk reduction while minimizing project and facility lifetime cost impacts.

The case study is hypothetical and consists of a capital project associated with a new facility processing flammable and toxic materials. The facility has public receptors to the south and west, is landlocked to the north, and has space for expansion to the east. The

FIGURE 8 Example toxic gas dispersion and a toxic refuge building.

hypothetical facility has a Crude Unit, a Naphtha Unit, an Ammonia Unit, associated Utilities, and storage/truck loading facilities.

5.1 | Layout and spacing

Based on the preliminary hazard review for the three main units present, it was determined that there are explosion, flammable/fire, and toxic hazards present at this facility. The facility will have two Central Control Buildings (CCBs)—one for the Naphtha and Crude units, and one for the Ammonia and Utility units. Access to the site is from the north, the topography is flat, and the wind blows predominantly from the southwest. For the preliminary site layout, see Figure 9.

Based on the knowledge of Subject Matter Experts (SMEs), the capital project team qualitatively defined a preliminary estimate of hazardous impacts. For more information on this process, see the 2020 paper on this topic. Engineering judgment suggests the following[17]:

A. Access and traffic must enter from the north.
B. Toxic releases can reach outside the fence line.
C. Hydrogen is present both as a pure supply and a major component of mixtures; therefore, deflagration-to-detonation (DDT) explosions are possible.
   a. Likely pressures >10 psig possible around areas of congestion/confinement.
   b. Potential for full site to experience pressures >0.9 psig, ruling out the ability to use light wood trailers per API RP 753.[3]
D. Concentrations above the lower flammable limit (LFL) are likely to reach beyond site boundaries.
E. Thermal radiation at high intensity (>37 kw/m^2) is likely at or beyond the facility fence line.

5.2 | Facility siting study (consequence and risk-based)

For a greenfield facility like that described in this case study, the documentation to conduct a facility siting study to determine site hazards and risks is available in a preliminary format in the detailed engineering portion of the capital project (Define FEL-3, as described in the 2020 referenced paper). Therefore, it is at this phase that the preliminary facility siting study should be conducted with the goal of identifying hazard and risk concerns; reviewing risk mitigation options to determine cost-effective mitigation options, where applicable; defining occupied building design requirements; and confirming risk compliance based on the site layout and associated hazards.

At this stage of the project, one of the important facility siting-based decisions to be made is the design parameters of critical buildings, namely the two CCBs. The reason for the importance of this information is twofold: first, in the event of an incident, the ability to maintain occupancy to safely shut down the facility in these locations is essential; and second, the design and construction of control buildings is often a significant investment for capital projects.[17] For the purposes of demonstrating how the results of a facility siting study can be successfully implemented, the CCBs will be reviewed. Note that the same concepts apply for facility siting studies conducted for existing facilities. Control buildings are often critical buildings for both safe operations of the facility as well as protection of personnel; therefore, ensuring that multi-hazard occupant vulnerability is reviewed in a similar manner, albeit a different process, is essential.

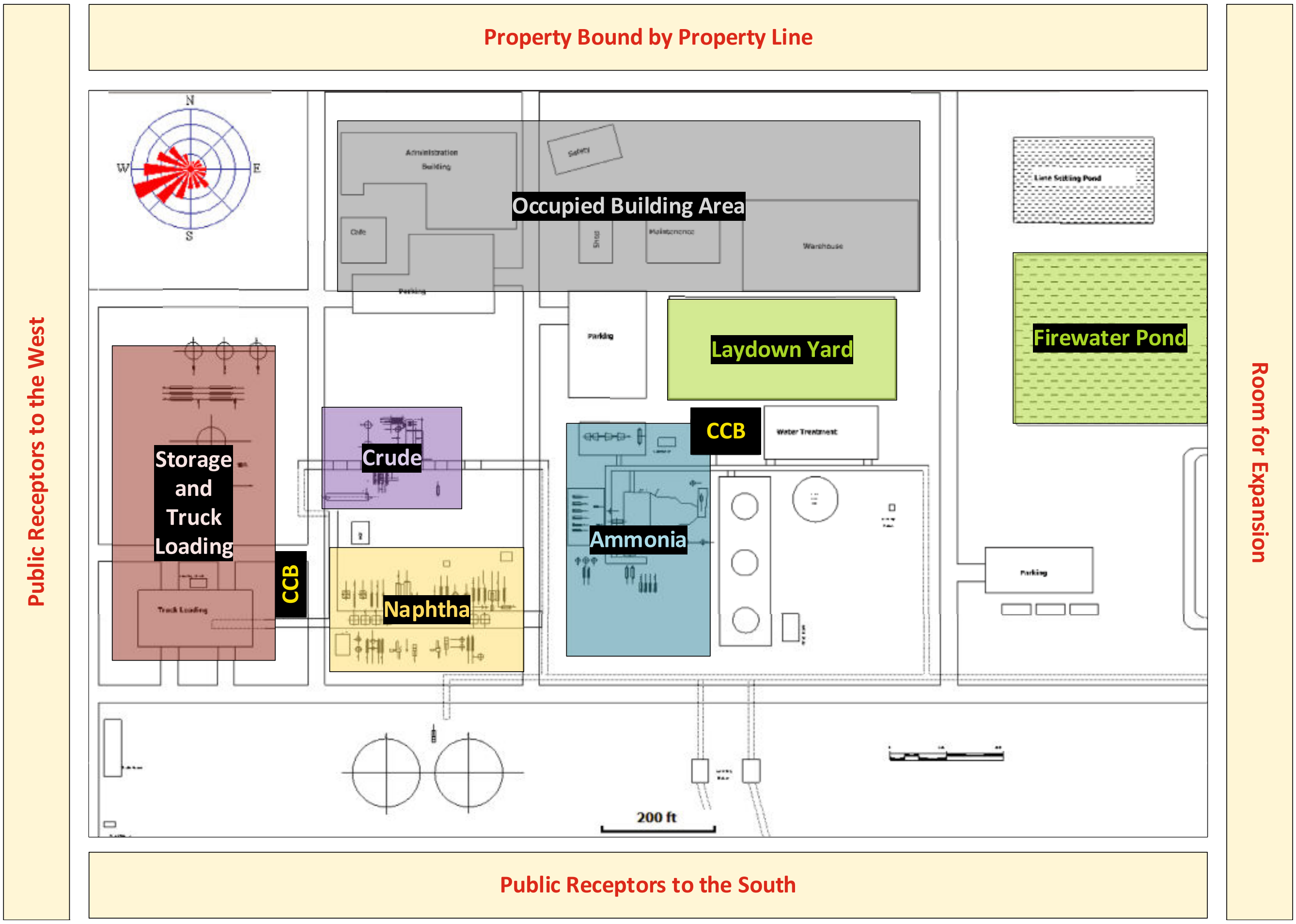

FIGURE 9 Site layout and spacing.[17]

The consequence-based facility siting study defines a range of hazards for facility operations based on a predefined methodology and determines the maximum hazards. The CCBs, which are occupied and critical to operations, are to be designed based on hazard exposure in anticipation of increased future staffing as well as anticipated future facility expansion, both of which will increase the risk profile for the CCBs.

The maximum hazards for the two CCBs are shown in Table 3. Due to the hazards present, API RP 752 indicates that the CCBs will need to be designed as Safe Haven locations with protection from blast, thermal, and gas ingress (flammable and toxic). Therefore, the specifications for the Detail Design phase of the project are to design the control buildings to maximize leak tightness, be designed for the blast loads shown in Table 3, and be constructed from materials that are thermal resistant.

Due to the multi-hazard protection requirement for the two CCBs, FORTRESS MRBs are specified as the building design requirements. Uniquely, FORTRESS has been subjected to a full-scale testing program to confirm that occupants of the building are exposed to negligible vulnerability for design basis events. Based on the FORTRESS design specifications, the protection from these buildings includes the following:

A. *Blast:* 8 psi overpressure at > 200 ms (long duration), negligible occupant vulnerability.
   a. ASCE Low Response (i.e., <1-degree of wall rotation) for the design load.
B. *Fragmentation:* 13 lb. projectile at 171 ft/s (116 mph) velocity.
   a. Very minor local spalling observed.
C. *Thermal:* 1-hour direct impingement for ¼-inch saturated propane jet fire.
   a. Local spalling observed on the building exterior, but internal air temperature < 110°F and negligible smoke/toxic off-gassing.
   b. Tested at thermal radiation levels well beyond 37.5 kW/m^2.
D. *Toxic:* < 0.1 ACH infiltration for main building and <0.03 ACH infiltration for interior Shelter-In-Place (SIP) room.
   a. SIP Control Box, designed and engineered to provide system specification.
E. *Extreme Weather:* Resistant to high wind and debris from hurricane and tornado natural hazards.

The risk-based facility siting aggregate (societal) risk results for the CCBs are shown in Table 4. This table indicates that the CCBs, as designed, are below risk tolerance criteria; however, it will be up to the project team to ensure due diligence is taken to ensure the buildings are constructed and operated to the specifications used in the facility siting modeling.

The full site risk profile is plotted in Figure 10 as a frequency-number of facility (FN) curve. An FN curve plots the frequency (F) of how often events occur on the vertical (y) axis and the number of fatalities (N) associated with the cumulative frequency on the horizontal (x) axis. This FN curve helps visualize the risk of catastrophic events by showing how frequently we may expect events showing a certain number of fatalities or more. Furthermore, Figure 10 breaks the total site risk into risk by hazard type to focus on ways to best reduce or mitigate risk. This figure indicates that blast events, both Vapor Cloud Explosions (VCEs) as well as vessel ruptures and the AN Neutralizer runaway reaction drive the risk profile for the site. Therefore, any risk mitigation options investigation should address lowering the blast risk profile for indoor and outdoor populations.

TABLE 3 Maximum hazards for example facility CCBs.

		Maximum hazard exposure			
Building	**Average occupancy**	**Blast**	**Thermal**	**Flammable**[a]	**Toxic**[b]
Crude/naphtha CCB	2.78	4.7 psi, 54.2 psi-ms	>37.5 kW/m^2	>UFL	>90% OV
Ammonia/utilities CCB	2.78	8.0 psi, 142.5 psi-ms	>37.5 kW/m^2	>UFL	>90% OV

[a]UFL – upper flammable limit.
[b]Occupant vulnerability.

TABLE 4 Maximum hazards for example facility CCBs – FORTRESS construction.

	Societal risk (fatalities per year)				
Building	**Blast**	**Fire**	**Flammable**	**Toxic**	**Total**
Crude/naphtha CCB	Negligible	4.7E-8	1.6E-9	2.6E-8	7.5E-8
Ammonia/utilities CCB	Negligible	2.3E-7	2.3E-9	3.2E-7	5.5E-7

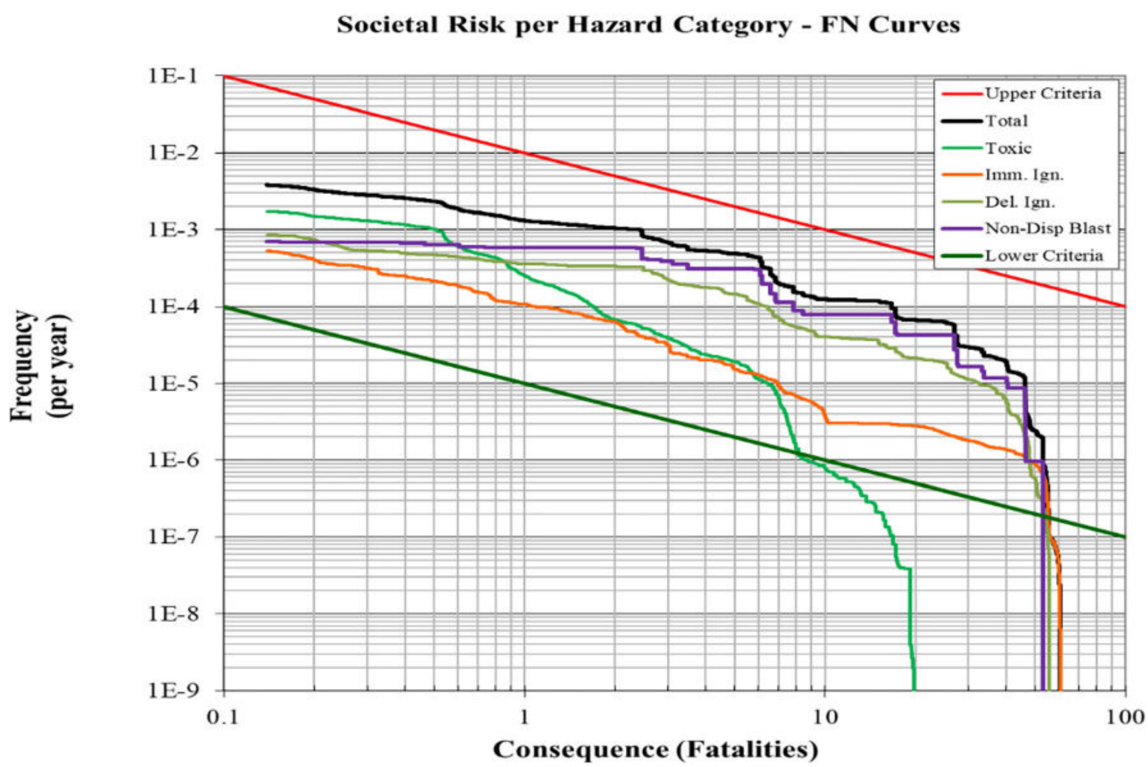

FIGURE 10 Facility QRA results – FN curve total and by hazard type.

6 | CONCLUSION

The release of the updated API RP 752/753 in January 2024 contains increased guidance on how to analyze occupied buildings for not only blast, but also fire and toxic impacts. Furthermore, there is now a clear discussion on building response versus occupant vulnerability and the requirement to document the correlation, depending on the way analysis is completed. To understand the impacts on vulnerability and not locate buildings based on impacts to people would be counterintuitive to properly applying facility siting to a given facility.

The results of the case study show that both CCR building locations have high hazard impacts, not only for blast, but also for fire and toxic hazards. However, because the project team knew early on in the capital project lifecycle to specify MRBs designed for high hazard locations, they were able to incorporate this requirement into the design and avoid costly design changes during the detailed design phases.

The number one takeaway from this paper should be that when implementing the results of a facility siting study to either design a new building or upgrade an existing building, the most important factor is to release a detailed building specification with precise requirements for blast, fire, toxic, and other hazards as part of the Request for Proposal process. If the building design requirements for facility siting are not properly stated, procurement may select an inferior building product that does not properly address all the facility siting results hazard types. Furthermore, if a certain vulnerability rating is required, then that must be explicitly stated. Resources are available for support with respect to constructing a building specification package for an MRB; for more information, please contact the authors of this paper.

FUNDING INFORMATION

There was no funding associated with this article.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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How to cite this article: Vilas KR, Mander T. Building design requirements for multi-hazard protection. *Process Saf Prog*. 2025;1-12. doi:10.1002/prs.70001