WHITE PAPER

THE NEXT STEP IN THE EVOLUTION OF BLAST RESISTANT BUILDINGS

The Development of Design Requirements for BRBs

REDGUARD®

BRB

BLAST-RESISTANT BUILDING

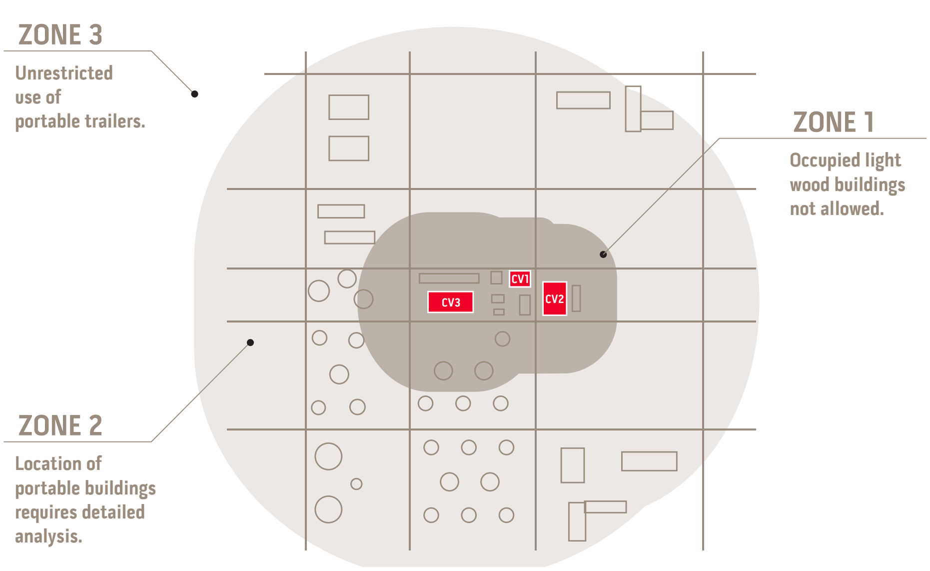
INTRODUCTION

The Blast Resistant Building (BRB) industry continues to strive to provide the ultimate in protection for workers, their companies, and their communities. This emerging industry has made great advancements in understanding the anatomy of a blast which has improved the design and performance of BRBs. But, as the industry continues to progress, it is now time to define the design requirements necessary to ensure that these technological and scientific advancements are put to use and that the buildings on-site meet a series of uniform guidelines. To that end this paper will explore the need for clear, concise design requirements in the following areas: implementation of a classification/rating system, acceptance of low and medium building response levels only, required blast testing, certification of engineers and testing facilities, and the use of approved quality management systems and manufacturing processes.

BACKGROUND

There will always be inherent dangers associated with the refining of petroleum products and the manufacture of certain chemical compounds. One of the most devastating of these dangers is the ever-present risk of explosions within these facilities. Many consider the explosion in BP's Texas City refinery in 2005, which resulted in the death of 15 and injury to more than 180 others, to be a major turning point in the adoption of new and additional safety processes and procedures. Even with an increased focus on Process Safety Management (PSM) in the years since the Texas City disaster, the risk of explosions remains. In 2013, explosions in places such as Geismar, LA; West, TX; Pascagoula, MS; Alsip, IL; and Donaldsville, LA accounted for the deaths of 19 people and injury to 285 others. Unfortunately, these dangers cannot be completely regulated out of the industry nor can companies re-engineer the volatile reactions out of the processes completely. As such, mitigation of these risks becomes a primary means to reaching the overriding objective, which is to increase safety in oil, gas, or petrochemical (OGP) facilities.

The process of mitigating these risks has taken many shapes and involved a number of agencies and industry groups over the years. Many improvements have been made to the processes and new requirements have been added to increase the level of protection afforded to the workers in OGP facilities. Even with this increased focus on PSM the use of blast resistant buildings is recommended within these facilities. The use of BRBs within OGP facilities improved significantly due to the publication by the American Petroleum Institute (API) of Recommended Practice (RP) 752 and 753. RP 752 covers the management of



hazards associated with the location of process plant permanent buildings. RP 753 covers the same topic but for portable buildings. Prior to the issuance of RP 753 many of the portable facilities used within a refinery or other OGP plants were light wood trailers. The implementation of RP 753 was a great step in ensuring additional safety by requiring that these light wood trailers be moved outside of the blast zones at the facility and that the only occupied buildings within these dangerous zones are BRBs. The publication of RP 752 and RP 753 greatly improved worker safety and created a new industry to supply these buildings to owners and contractors operating within the volatile facilities. However, as with any new advancement in technology, the initial solution needs to be continually evaluated and modified as the technology and understanding of the blast science evolves to ensure that the greatest level of protection is afforded to the workers, companies, and their communities.

"The primary objectives for providing blast resistant design in buildings are: personnel safety; controlled shutdown; and financial consideration."

American Society of Civil Engineers (ASCE)

In the American Society of Civil Engineers (ASCE) publication, *Design of Blast-Resistant Buildings in Petrochemical Facilities*, it states, "The primary objectives for providing blast resistant design in buildings are: personnel safety; controlled shutdown; and financial consideration." In studying the topic of blast resistant buildings for use in an OGP facility there are a large number of books, papers and publications including RP 752 and RP 753, which advise the use of blast resistant buildings. However, there is no document which defines what characteristics and practices are necessary to clearly ensure a blast resistant building provides the most suitable level of protection in a given scenario in order to best meet those three primary objectives. These numerous documents provide a plethora of information pertaining to the siting, science, and mathematical equations behind the design of blast resistant buildings, but with the volume of paper, hours of effort, and a proficient understanding of engineering needed to decipher all of this information, it still remains very difficult for the end user to understand exactly what they need in a blast resistant building to best protect their personnel, their community and their company's finances. With such large stakes, the industry needs a design requirement to ensure that the right building is built, with the right level of protection, and is in use in the right place should a blast event occur.

BLAST RESPONSE

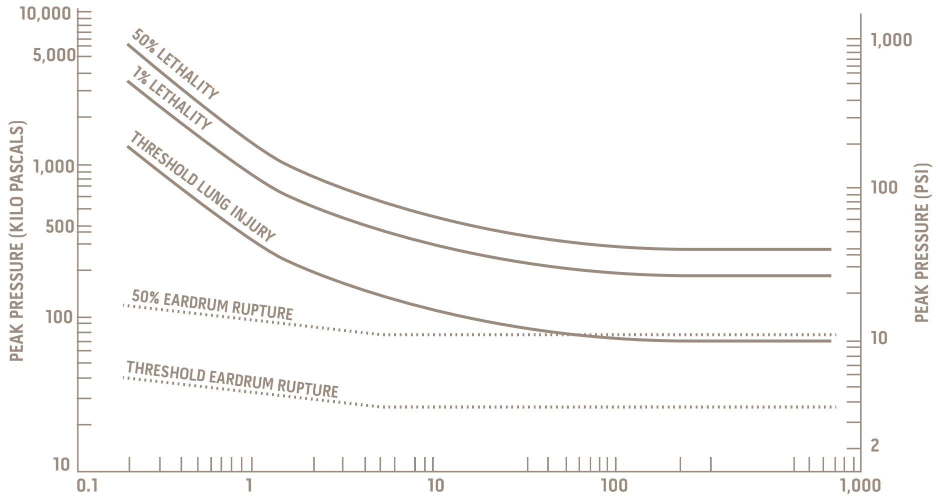
To protect the occupants of the building, one must first understand what occurs during a blast event and the types of injuries that stakeholders are trying to prevent. There are several key factors which independently or jointly factor into whether or not an occupant survives and the types and severity of the injuries encountered. These key factors are best described as a response to the blast, and include areas such as building response, human response, and nonstructural response.

In the American Society of Civil Engineers (ASCE) publication, Design of Blast-Resistant Buildings in Petrochemical Facilities, a building's response to a blast event is categorized into one of three response levels. These response levels range from low response (low damage) to high response (catastrophic damage).

In reviewing these definitions there are distinct differences between low, medium, and high response.

RESPONSE LEVELS	
LOW RESPONSE (LOW DAMAGE)	1) Localized building/component damage. 2) Buildings can be used, however repairs are required to restore the integrity of the structural envelope. 3) The total cost of repair is moderate.
MEDIUM RESPONSE (MEDIUM DAMAGE)	1) Widespread building/component damage. 2) Buildings cannot be used until repaired. 3) The total cost of repair is significant.
HIGH RESPONSE (HIGH DAMAGE)	1) Building/component has lost structural integrity. 2) Buildings may collapse due to the environmental conditions. 3) The total cost of repairs approaches replacement cost of building.

Table 5.B.1.A: Building Damage Levels as taken from Design of Blast-Resistant Buildings in Petrochemical Facilities by American Society of Chemical Engineers (ASCE), 2nd Edition, 2010.



Courtesy of Bowen TE and Bellamy RF, eds, Emergency War Surgery. Washington, DC : United States Government Printing Office, 1988.

The high response rating involves a loss of structural integrity , and represents the beginning stages of collapse. Crush injuries and deaths caused by collapsed structures falls under the quaternary blast injury category, which is one of four categories of blast injuries defined by medical professionals. The other three categories of blast injury include; primary, secondary, and tertiary. The human body has been shown to be able to survive, although with considerable damage, the effect of a 30 psi blast wave , however, the collapse of a building can ultimately bring about loss of life in an otherwise survivable incident.

Primary blast injuries are caused solely by the direct effect of blast overpressure as applied to the body's tissues, or otherwise, human response. When the leading edge of the blast wave reaches a person, it causes a large immediate increase in ambient pressure. Since explosive gases continue to expand from the origin of the blast, a longer negative underpressure follows the positive overpressure. Both the positive overpressure and the negative underpressure can cause significant injuries, up to and including death. The most common injuries occur within the gas-containing organs due to the air contained within these organs being compressed by the pressures from the blast wave. The most susceptible organs include the lungs, gastrointestinal tract, and middle ear.

One of the most widespread injuries associated with an explosion is eardrum damage which can result in the loss of hearing and potentially render the victim deaf. The eardrum will typically rupture when the overpressure exceeds 5 psi , which is significantly less than the overpressures possible in many OGP facilities.

Even when a worker is in a building, they are not saved from an increase in the overall pressure changes caused by a blast event. The way a building reacts during the blast event is a significant factor in how those pressures are mitigated, or not, even to those inside of a BRB. The pressure inside of a building can change significantly based on building design and how much deflection occurs to the walls when impacted by the blast overpressure.

When exposed to the higher overpressures possible in the OGP facilities, the eardrum may be destroyed and the ossicles, or bones of the inner ear, can be dislocated or fractured. Even explosions where overpressures have remained below 5 psi, the eardrum has been shown to bleed even without fully rupturing.

Pulmonary barotrauma is the most common cause of a fatal primary blast injury. Pulmonary barotrauma includes many associated injuries such as pulmonary contusion, systemic air embolism, thrombosis, lipoxygenation and disseminated intravascular coagulation. This list of primary blast injuries is extensive and severe, but even if these injuries could be reduced to zero, the risk of injury or death during a blast does not disappear, as the leading cause of injury and death in a blast event is actually from secondary blast injuries.

Secondary blast injuries are those injuries caused by debris propelled by the blast wave (nonstructural response) which results in both penetrating injuries and blunt force trauma to the victim. A person who survives the initial blast wave can be killed or maimed by the flying debris. The chart below shows the low levels of weight, velocity and energy required for flying debris to critically injure specific body parts.

CRITICAL ORGANS	WEIGHT (LBS.)	FRAGMENT VELOCITY	ENERGY (FT-LB)
THORAX	>2.5	10	4
	0.1	80	10
	0.001	400	2.5
ABDOMEN & LIMBS	>5.0	10	9
	0.1	75	9
	0.001	550	5
HEAD	>8.0	10	12
	0.1	100	16
	0.001	450	3

From Table 1-3 of Threshold of Serious Injury to Personnel Due to Fragment Impact; Unified Facilities Criteria; UFC 3-340-02; Structures to Resist the Effects of Accidental Explosions; 5 December 2008

This debris can be made up of any number of components occurring naturally and regularly within the refinery or petrochemical environment. It can be made up of metal shrapnel from the origin of the blast, glass from buildings and vehicles, and even everyday office equipment and supplies. For example, the glass façade on the Alfred P. Murrah Federal Building in Oklahoma City shattered into thousands of pieces which were propelled throughout the building during that blast causing devastation to many of the building occupants who had survived the initial explosion.

The glass on a blast resistant building should be designed to withstand the blast wave and not shatter as the façade in Oklahoma City did. Nevertheless, could a heavy operations binder on a shelf above a desk, or an unsecured desk, itself, cause injuries when propelled across a busy office? From the preceding chart, the answer to that question is yes, since an object weighing only 0.1 lbs can cause a severe head injury when traveling at 100 fps. During a blast event, the walls of a BRB will deflect, by design, to dissipate the forces being applied to the structure. When this occurs, the deflection can cause the outside wall to move several inches which, in turn, can cause objects mounted to those walls, such as mirrors, shelves, and cubicles, to become projectiles.

The primary reason for requiring the use of blast resistant buildings on an OGP facility is to mitigate the potential risk of injury or death to the personnel on site. But do all blast resistant buildings provide the same level of protection from primary, secondary, tertiary and quaternary blast injuries? If not, how does the facility know that it has the right building, built right, with the right level of protection, sitting in the right place should a blast occur? These questions persist within this industry, and rightfully so, as the stakes could not be greater to the personnel working at the facility, to the community in which the facility is located, or to the financial wellbeing of the owner-operators.

In many industries, when lives are on the line, and safety is paramount, there are specific industry groups who have developed design requirements to include testing, manufacturing and quality in order to ensure that all parties involved have a clear and uniform understanding of what the product can and cannot do to mitigate the potential for injury or death in their hazardous environment.

EVOLUTION OF DESIGN

Several examples exist, which show more mature industries progressing through the development of design requirements and practices. These guidelines, in turn, advance the industry and the level of safety and protection afforded to those who rely on these products to make it home each night. One good example of this is with ballistic body armor.

In the mid-1970s, The National Institute of Justice (NIJ) began developing performance requirements for body armor to help provide confidence to the law enforcement community so that officers could consistently receive the protection they deserve each and every time they are faced with gunfire while on duty. Today, NIJ is tasked with researching, developing and maintaining the domestic standards for ballistic body armor. NIJ Standard-0101.06, "is a technical document that specifies the minimum performance requirements that equipment must meet to satisfy the requirements of criminal justice agencies and the methods that shall be used to test this performance. It can be used by body armor manufacturers and purchasers to help determine whether specific models meet the minimum performance standards and test methods identified". This design guide was produced as part of their Standards and Testing Program.

DESIGNED RATING SYSTEM

The NIJ Standard-0101.06 establishes a classification system to delineate the varying levels of protection provided by different products or designs. This published classification system allows a manufacturer or end user to know what level of specific threat the body armor is designed and tested to withstand. If a law enforcement officer determines that he needs protection from a .357 Magnum, then he can quickly determine that he needs a product that is certified at NIJ Level II. It does not matter which manufacturer is chosen or how a company's marketing department has decided to advertise their product, NIJ Level II means that he is protected from a round from a .357 Magnum.

In comparison, within the blast resistant building industry, there is no guide which can be used to determine precisely the level of protection provided by a particular building. Site studies are performed at the OGP facility to determine the threat level based on the specific processes occurring at that location. Once the threat level has been determined, it is then the end user's responsibility to find a building that protects occupants at that level, without the benefit of a rating system as part of an overall design guide.

ARMOR TYPE	TEST ROUND	TEST AMMUNITION	NOMINAL BULLET MASS	MIN. REQUIRED BULLET VELOCITY	NO. OF SHOTS	NO. OF TESTS
II-A	1	9MM FMJ	8.0G 124GR	373M/S (1225 FT/S)	6	4
	2	40 S&W FMJ	11.7G 180GR	325M/S (1155 FT/S)	6	4
II	1	9MM FMJ	8.0G 124GR	398M/S (1305 FT/S)	6	4
	2	357 MAG. JSP	10.2G 124GR	436M/S (1430 FT/S)	6	4
III-A	1	357 SIG FMJ FN	8.1G 125GR	448M/S (1470 FT/S)	6	4
	2	44 MAG. SJHP	15.6G 240GR	436M/S (1430 FT/S)	6	4
III	1	7.62MM NATO FMJ	9.6G 147GR	847M/S (2780 FT/S)	6	2
IV	1	.30 CAL M2 AP	10.8G 166GR	878M/S (2880 FT/S)	1	2

Table 4; P-BFS performance test summary; National Institute of Justice (NIJ) Standard 0101.06; Ballistic Resistance of Body Armor; July 2008

Most manufacturers currently use some sort of combination of pounds per square inch (psi) measurement and a duration of time, expressed in milliseconds, (msec) in which that pressure is applied. But even if the language appears to be similar from one manufacturer to the next, simple nuances exist which can drastically change the comparison. For instance, a blast resistant building can be engineered to withstand a blast of 5 psi for 200 msec. That same building could also be advertised to withstand a blast of 5 psi at 500 psi-msec which could also be a correct calculation. One description communicates the duration and the other the impulse, or measure of energy of the blast event (psi-msec), but to many in the OGP industry that difference is lost, and the 500 psi-msec impulse appears to signify a more substantial building than the 200 msec duration rating even though both ratings can apply to the same building with the only difference being what is calculated. This simple nuance can lead to confusion and possible acceptance of an inferior level of blast protection. The industry would benefit greatly if a design guide were developed so that the manufacturer, owner-operators and end users all knew exactly what level of threat a building was designed to withstand. By eliminating inconsistencies and providing this much-needed rating, the industry can make great strides to reduce the number primary and secondary blast injuries from occurring.

Most manufacturers currently use some sort of combination of pounds per square inch (psi) measurement and a duration of time, expressed in milliseconds, (msec) in which that pressure is applied.

The variation in building response levels, or the lack of understanding of their meaning, adds additional confusion surrounding the level of protection provided by a blast resistant building. As previously discussed, the differences between low, medium, and high response can be extremely significant in the overall protection of personnel housed within a particular building. However, a building is deemed to be "blast resistant" at all three levels.

Continuing the comparison with the ballistic body armor industry, they have addressed a similar scenario in regards to backface deformation. Backface signature (BFS) or backface deformation is the term used to describe the transfer of energy from the bullet to the wearer of the body armor even when the bullet does not penetrate the body armor. This means that even though the vest stopped the bullet from penetrating the wearer's body, the transfer of energy from that bullet is felt by the user of the vest. This backface deformation has been shown to cause severe injury due to the blunt force trauma as a result of the transfer of energy. As such, NIJ standards include testing for BFS and have established an upper limit as to the amount of impact allowable to meet the standard.

In similar fashion, blast resistant buildings should have an upper limit on the building's intended response. Design requirements would help ensure that redundancy is engineered into the building and therefore the loss of structural integrity, or near collapse, is no longer a concern. If the overriding purpose of using blast resistant buildings is personnel safety, controlled shutdown, and financial consideration, then allowing an occupied building to be designed to a high response level without the necessary redundancy should no longer be permitted. This one step could greatly reduce the number of quaternary injuries resulting from blasts in the refinery or petrochemical environment and save lives.

TESTING BY DESIGN

Having both a classification system and an upper limit of the building's response would be a great step forward in advancing this industry. But, to ensure that a blast resistant building meets the advertised and needed level of protection, testing would need to be required. Again, the ballistic body armor industry has already progressed through this stage. NIJ Standard-0101.06 includes an extensive testing procedure to ensure that each product on the market meets the stringent requirements necessary to protect human life.

The NIJ specification includes the testing procedures for each level of classification as well as specifying the layout of the testing facility, the equipment to be used, how to properly measure and monitor the results, and even how to properly label a compliant product. For example, once the test range has been configured as required in the standard, the testing on an NIJ Level II vest can begin. For that vest to be certified it must be able to withstand, not just a single bullet from a .357 Magnum, but each sample is tested to withstand 6 shots from a .357 Magnum at a velocity of 1340 ft/s +/-30 ft/s and 6 shots from a 9mm at a velocity of 1245 ft/s +/-30 ft/s. This type of detailed testing helps to ensure that if that product is ever put to a real test that it will protect the user as stated.

Testing products to this level of scrutiny within the blast resistant building industry is necessary given the impact an explosion could have on each of the stakeholders. The ability for the buyers and end users to know that the buildings they have in place are not only designed to withstand a particular size of blast, but have been proven to withstand it, goes a very long way toward protecting lives and communities. Performance of a blast test verifies a manufacturer's basic design and permits that manufacturer to use proven values in their engineering on future projects. These measurements show exactly how a building will react during a blast, including wall deflection and internal pressure measurements which are crucial in preventing primary and secondary blast injuries to the occupants.

As the blast protection industry continues to expand, more and more resources are put toward new developments and with that comes new knowledge and better understanding of how to offer greater levels of protection. But without a procedure in which to test these new discoveries, we have no way to know for certain that these advances are truly improving the resiliency of blast resistant buildings.

In addition to specifying the testing process for ballistic body armor, NIJ takes it a step further by requiring that laboratories performing ballistic testing are approved through an accreditation process to meet specific technical requirements. This additional approval process provides real oversight to the testing process and is just one additional step to ensure that the results received are true and accurate.

In the blast resistant building industry, the terms "designed" and "engineered" are used almost interchangeably to describe that the blast resistant building has been reviewed by an engineer and found to have the ability to meet or exceed the blast resistance requirements of a particular situation or scenario. These terms do not mean that a building has been tested to withstand these exact requirements, nor do the terms mean that the building was designed or engineered by anyone holding more than a structural engineering degree, as there are no degrees currently available for blast resistance engineering. Due to the overall vagueness of these terms, and the uncertainty of knowing the skill level of the engineer declaring a building as blast resistant, it would be most pertinent to develop a process in which to approve engineers and/or their firms as certified blast resistance engineers.

It will add a much-needed level of expertise and assurance that the occupants of a building being put on a particular site will be protected from all categories of blast injuries, when the requirements of testing a manufacturer's basic design are combined with design by a certified engineer.

QUALITY CONTROL BY DESIGN

In addition to the testing and design certification, improvements can be recognized in the monitoring of quality within the manufacturing process. A building can have the best design imaginable, but if it is not manufactured with a high level of quality then all of the testing and design work does not matter. The quality of manufacturing or constructing a blast resistant building is important to maintain throughout the construction of all buildings. Careful attention to detail and oversight of each step in the process must remain consistent from the first building produced through the one thousandth building.

The ballistic body armor industry has implemented a program to similarly address the quality issue. The Follow-Up Inspection and Testing Program began in 2010. This program subjects newly manufactured armor samples to the same ballistic testing as the original samples passed and then compares the construction of newly made armor with samples evaluated during the initial testing. This double testing process provides confidence that body armor coming off the assembly line is manufactured consistently and performs in accordance with NIJ standards.

"The follow-up program provides an additional set of eyes and ears into the manufacturing process," said Lance Miller, NLECTC-National director. "We want to ensure that the men and women who wear these vests on a daily basis have as much confidence in these products as we can possibly give them."

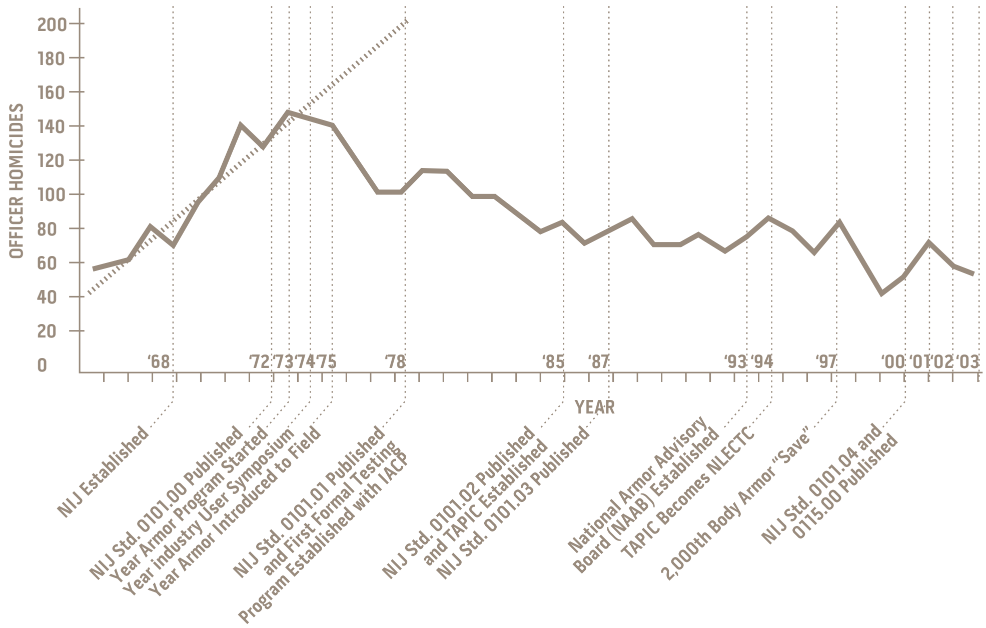
Testing blast resistant buildings twice, even if the second test is random, could get extremely expensive. However, that does not mean that the blast resistant building industry should not still consider adding additional quality inspection requirements to the manufacturing process. The industry should look to adopt a proven approach to drive a culture of quality. By adopting a proven and well established system such as ISO 9001, and requiring manufacturers to certify their quality management systems in accordance with this standard, this industry could also assure its users of enduring confidence.

SUMMARY

As the blast resistant building industry continues to develop, there are many new discoveries and improvements made each year. As this market grows along with these new advancements there becomes a time where the industry must look inward to re-evaluate where it is headed and how to get there. That time for introspection is now, before another life is lost.

The preceding pages have compared and contrasted the design requirements of the ballistic body armor industry with that of the blast resistant building industry. The first impression may have been that there were not many similarities between these distinctly different fields. But, as the point has been illustrated in this white paper, the ultimate goal of those working in both industries is to mitigate risks by ensuring that the greatest level of protection is afforded to the workers, companies, and their communities.

The late 1960s and early 1970s were a dangerous time to be a law enforcement officer in the United States. From 1968 to 1973, the homicide rate for law enforcement officers increased from 60 per year to nearly 120 per year. At that time there was no affordable, dependable and comfortable body armor on the market which met the needs of the law enforcement community. NIJ's predecessor, the National Institute of Law Enforcement and Criminal Justice, began developing lightweight body armor in 1971 and began testing it in 1978. As part of this development process, NIJ published its first version of Ballistic Resistance of Body Armor Standard in 1972. This same standard (NIJ 0101) is now in its sixth revision and is the same document referenced throughout this paper.



Source: FBI Uniform Crime Reports: Law Enforcement Officers Killed and Assaulted, 2003, 2002, 2001, 2000,1999, 1998, 1997, 1996, 1995, 1994

As seen in the prior chart, the development of design requirements within the ballistic body armor market to include a rating system, testing procedures, and quality control processes have drastically and positively impacted that industry. It is because of the successes experienced by those organizations and companies, within the ballistic body armor market, that we set out today to implement a similar approach to the incorporation of a design guide within the blast resistant building industry. To ensure the continued ability to provide the level of protection required, it has become time to make certain that all buildings labeled and sold as blast resistant meet the appropriate requirements in order to safely know that the right building is built, with the right level of protection, and is in use in the right place should a blast event occur.

CONCLUSION

With each passing year, blast engineering continues to refine itself and the lessons learned continue to help steer the development of future products. By investigating these topics now, we can continue to push the industry forward to provide the best and safest blast resistant buildings. However, if a blast event were to occur when workers were housed in a blast resistant building that did not provide the level of protection necessary, and they were subsequently killed or injured (all the while thinking they were safe), the blast resistant building industry would change drastically under the additional scrutiny from government agencies, the media, and even the end users. If we can address these potential pitfalls within the industry now, we can prevent unnecessary injuries and deaths and avoid redundant oversight in the future. The first step in this process is to begin implementing design requirements today.

To ensure maximum protection against injury and death, the blast resistant building industry must move forward with the following proposed principles:

- Implementation of Classification/Rating System
- Acceptance of Low and Medium Building Response Levels Only
- Requirement for Blast Testing
- Certification of Engineers and Testing Facilities
- Use of Approved Quality Management Systems and Manufacturing Processes

The acceptance of these new guidelines is paramount for moving the blast protection industry forward and for reducing the number of injuries and deaths attributed to blast events within the OGP industry.

REFERENCES

[1] U.S. Chemical Safety and Hazard Investigation Board. Investigation Report - Refinery Fire and Explosion and Fire. BP Texas City March 23, 2005

[2]U.S. Chemical Safety and Hazard Investigation Board, Investigation Report- Williams Olefins Plant Explosion and Fire, June 14, 2013.

[3]Chappel, Bill (April 23, 2013). "Death Toll In West, Texas, Fertilizer Explosion Rises To 15".

[4]Associated Press (November 15, 2013). "Deadly Refinery Explosion, fire in Mississippi".

[5] Leventis Lourgos, Angie (December 13, 2013). "2 Hurt in Explosions, Fire at Southern Suburban Chemical Plant". Chicago Tribune.

[6]Friedman, Chandler and Botelho, Greg (June 15, 2013). "1 Killed, 8 Injured in Blast at Louisiana Chemical Plant". CNN

[7]API Recommended Practice 753 – "Management of Hazards Associated with Locations of Process Plant Portable Buildings", 2012

[8]American Society of Chemical Engineers (ASCE), Deign of Blast-Resistant Buildings in Petrochemical Facilities, 2nd Edition, 2010

[9]Blast Injury – Wikipedia. http://en.wikipedia.org/wiki/Blast_Injury.

EMT - Blast Injuries - Trauma, http://www.emsconedonline.com/pdfs/EMT-%20 BLAST%20INJURIES-Trauma.pdf, January 2014.

[10]Pennardt, Andre MD, FACEP, FAAEM, FAWM and Kulkarni, Rick MD. Blast Injuries Clinical Presentation. Medscape. April 2013.

[11]EMT - Blast Injuries - Trauma, http://www.emsconedonline.com/pdfs/EMT-%20 BLAST%20INJURIES-Trauma.pdf, January 2014.

[12]EMT - Blast Injuries - Trauma, http://www.emsconedonline.com/pdfs/EMT-%20 BLAST%20INJURIES-Trauma.pdf, January 2014.

[13]EMT - Blast Injuries - Trauma, http://www.emsconedonline.com/pdfs/EMT-%20 BLAST-20INJURIES-Trauma.pdf, January 2014.

[14]Pennardt, Andre MD, FACEP, FAAEM, FAWM and Kulkarni, Rick MD. Blast Injuries Clinical Presentation. Medscape. April 2013.

[15]Glenshaw MT, Vernick JS, Li G, Sorock GS, Brown S, Mallonee S. Factors associated with injury severity in Oklahoma City bombing survivors. J Trauma. Feb 2009;66(2):508-15.

[16]Ballistic Resistance of Body Armor NIJ Standard-0101.06, National Institute of Justice Standards, U.S. Department of Justice. July 2008.

[17]Table 4; P-BFS performance test summary; National Institute of Justice (NIJ) Standard 0101.06; Ballistic Resistance of Body Armor; July 2008

[18]Coppola, Michele R. Ballistic Body Armor: A closer Look at the Follow-up Inspection and Testing Program, NIJ Journal No. 271, February 2013

[19]Coppola, Michele R. Ballistic Body Armor: A closer Look at the Follow-up Inspection and Testing Program, NIJ Journal No. 271, February 2013

[20]FBI Uniform Crime Reports: Law Enforcement Officers Killed and Assaulted, 2003, 2002, 2001, 2000, 1999, 1998, 1997, 1996, 1995, 1994

RedGuard is in the business of protecting lives. Driven by a passion for product innovation, RedGuard prides itself on the development of solutions that raise the bar to protect customers across industries and around the globe. Its solutions include the world's largest fleet of successfully tested blast-resistant buildings, the industry's premier line of fully customizable blast-resistant buildings, solutions that protect those in the defense and security sectors, customizable modular buildings that grow with your organization, recent innovations in standardized and pre-engineered blast resistant suites, and a division that offers unmatched logistics and one of the largest fleets of portable storage units and fully customizable on-site offices. Learn why RedGuard is the industry's safety authority at RedGuard.com

REDGUARD®

4340 S. West St. • Wichita, KS 67217
855.733.4827 | 316.554.9000
redguard.com