T2 Laboratories Explosion Damage Assessment

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ABSTRACT

An explosion at T2 Laboratories Inc. in Jacksonville, Florida occurred at approximately 1:30 pm on December 19, 2007. The explosion killed four T2 employees and injured 32 workers at T2 and surrounding businesses. Debris from the reactor, which was the source of the explosion, was found up to one mile away, and the explosion damaged buildings within one quarter mile of the facility. ABSG Consulting Inc. (ABS Consulting) was contracted by the U.S. Chemical Safety Board (CSB) to 1) conduct a site survey to document blast related structural damage, 2) perform analysis to estimate explosion energy, and 3) develop overpressure and impulse contour maps.

The CSB approved this paper for release and presentation at the 2010 DDESB Explosives Safety Seminar.

1. Introduction

An explosion at T2 Laboratories Inc. in Jacksonville, Florida occurred at approximately 1:30 pm on December 19, 2007. ABS Consulting was contracted by the U.S. Chemical Safety Board (CSB) to 1) conduct a site survey to document blast related structural damage, 2) perform analysis to estimate explosion energy, and 3) develop overpressure and impulse contour maps.[1] The most severe blast damage, outside of the T2 Laboratories property, was observed at the properties immediately adjacent to T2 Laboratories.

T2 Laboratories was a small chemical facility that included a single process unit with a reactor vessel. The T2 Laboratories compound, shown in Figure 1, included a single operating unit which included a control room located north-east of the reactor vessel. The control room was constructed with concrete masonry unit (CMU) walls and a precast hollow core roof. The process reactor was a tall vertical cylinder of thick steel construction.

[1] U.S. Chemical Safety and Hazard Investigation Board, "Investigation Report, T2 Laboratories, Inc. Runaway Reaction", Report No. 2008-3-I-FL, September 2009.

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14. ABSTRACT
An explosion at T2 Laboratories Inc. in Jacksonville, Florida occurred at approximately 1:30 pm on December 19, 2007. The explosion killed four T2 employees and injured 32 workers at T2 and surrounding businesses. Debris from the reactor, which was the source of the explosion, was found up to one mile away, and the explosion damaged buildings within one quarter mile of the facility. ABSG Consulting Inc. (ABS Consulting) was contracted by the U.S. Chemical Safety Board (CSB) to 1) conduct a site survey to document blast related structural damage, 2) perform analysis to estimate explosion energy, and 3) develop overpressure and impulse contour maps.

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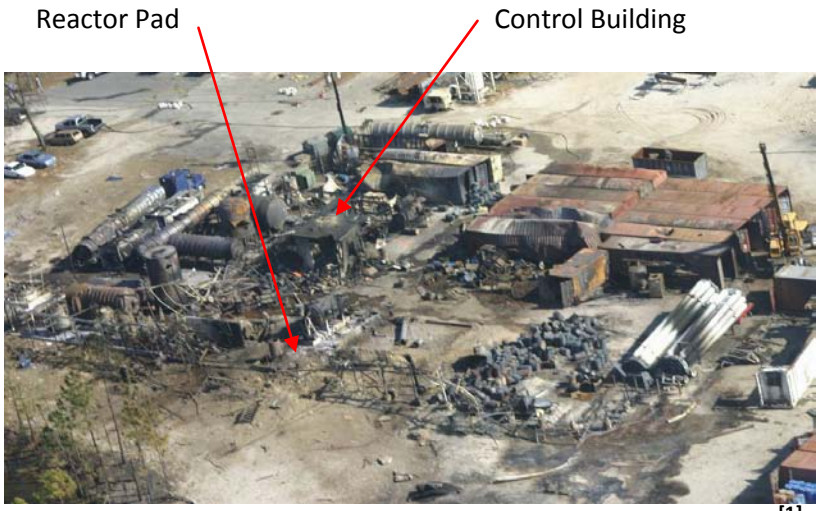


Figure 1. T2 Laboratories Post Incident Aerial Photograph [1]

The source of the explosion was established as a catastrophic failure of the reactor vessel, see Figure 2. The explosion threw many pieces of the vessel as missiles and generated a blast wave that swept across the surrounding area causing significant structural damage to several buildings off-site.

Figure 2. T2 Laboratories Reactor Head[1]

2. Methodology

ABS Consulting surveyed several damaged and undamaged Load Indicators. Load Indicators are structural components or elements that have been exposed to blast loading and may be analyzed to determine the combinations of overpressure and impulse necessary to produce the observed damage. Examples of Load Indicators include damaged buildings, deformed structural members (beams, columns, wall panels, etc.) and broken windows both at the explosion scene and at surrounding areas.

Load Indicators were analyzed in order to estimate the explosion energy. Load Indicators were sorted into two data sets in the analysis, including: 1) off-site structural building damage and 2) off-site window breakage. Explosion yield, in terms of lb_{TNT}, was calculated for each Load Indicator and separate average values were obtained for structural damage and window breakage.

An analysis of all measured damaged Load Indicators was performed using only the positive phase of the blast wave. The shape of a blast wave, from High Explosives (HE) such as trinitrotoluene (TNT), is a sudden rise in pressure which decays exponentially followed by a negative pressure with a smaller magnitude. A typical HE blast wave shape is shown below in Figure 3.

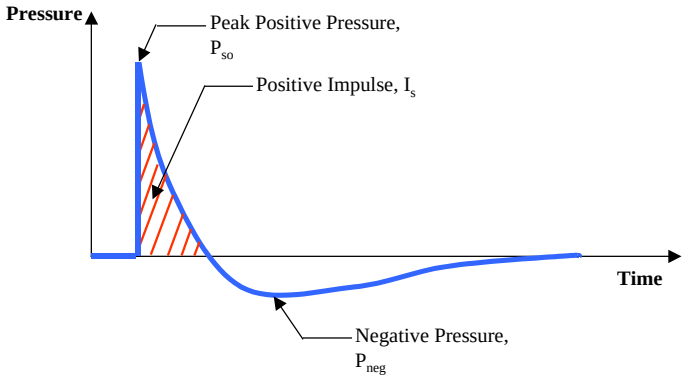


Figure 3. Typical Blast Load for High Explosives

Using the methods of Baker[2] for pressure vessel bursts (PVB), a scaled distance (Rbar) can be computed for each data point according to Equation 1, where p_0 is atmospheric pressure, R is the standoff distance to the given component, and E is the total explosive energy of the estimated TNT charge weight (W). The unit energy of TNT used in this analysis was 1.88×10^7 lbf-in/lb_{TNT}.

$$Rbar = Rp_0^{1/3} / E^{1/3} \qquad \textbf{Equation 1}$$

The PVB curves for pressure and impulse are shown below in Figure 4[2]. These graphs present curves for determining the pressure and impulse resulting from a pressure vessel burst which is dependent on the bursting pressure; these curves are shown graphically with the dashed lines. An additional curve for determining pressure and impulse for HE is shown on the graphs with a solid line.

The purpose of using the PVB graphs is to show that for the range Rbar values for the given damage data sets, there is no significant difference in using the HE curve versus the PVB curves. Calculated Rbar values for the data sets ranged from a minimum value of 2 to a maximum value of 10 for off-site damage indicators. This range is shown graphically in the PVB curves[3] below in Figure 4 to be well within an acceptable operating range for TNT equivalence. As can be seen in these figures, in the range of computed Rbar values, the scaled pressure and impulse values from pressure vessel burst closely mimic the values of the scaled HE curves. In addition, Cain and Hall[4] state that the blast wave emanating from a bursting pressure vessel is similar to that caused by a high explosive detonation. This demonstrates that using a TNT charge weight as a source of explosion was a valid approach for

[2] Baker, W.E., Cox, P.A., Westine, P.S., Kulesz, J.J., and Strehlow, R.A., "Explosion Hazards and Evaluation," Fundamental Studies in Engineering 5, Elsevier Scientific Publishing Company, 1983.
[3] Tang, M.J., Cao, C. Y., Baker, Q. A., "Calculation of Blast Effects From Bursting Vessels."
[4] Cain, Maurice and Hall, Robert. "Pressure Vessel Burst Test Study", PVP-Vol. 277, Recertification and Stress Classification Issues, Book No. G00845, 1994.

this explosion incident for the measured damage indicators in the operating range highlighted in Figure 4.

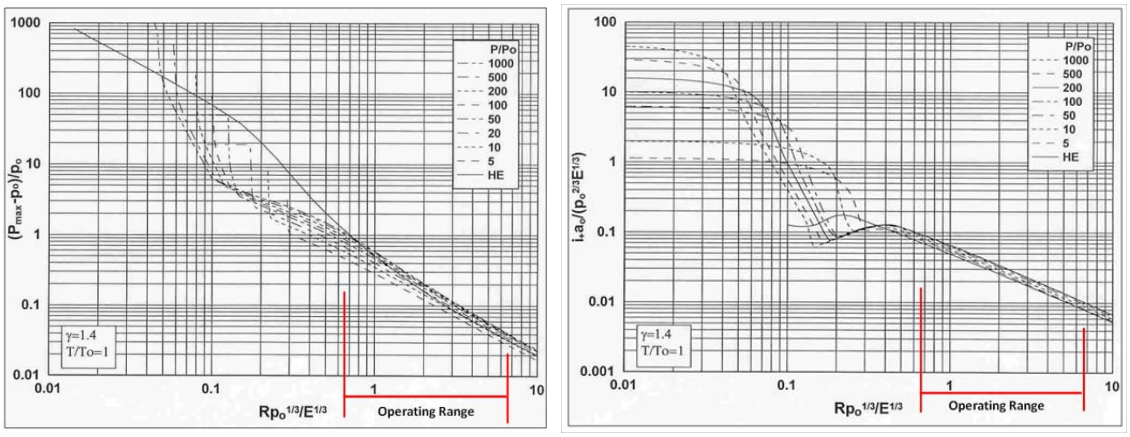


Figure 4. Pressure and Impulse Relationships vs. .Scaled Range for Pressure Vessel Burst[3]

A dynamic elastic-plastic single-degree-of-freedom (SDOF) analysis was performed for each structural Load Indicator using the U.S. Army Corps of Engineers' SBEDS[5] computer program. For each structural component, a standoff distance was measured to the component centerline from the center of the reactor vessel using a scaled aerial map. An example of how the standoff distances used in analysis were measured is shown below in Figure 5. An iterative analysis using the TNT blast curves and SBEDS analysis was conducted to find a TNT energy that is consistent with the damage to the component at that distance. The measured permanent deformation of a given component was compared to the resistance-deflection response curve, as shown in Figure 6. This procedure was repeated for each component.

Figure 5. Component Standoff Distance Measured to Centerlines

[5] PDC-TR 06-08, "Single Degree of Freedom Response Limits for Antiterrorism Design", U.S. Army Corps of Engineers Protective Design Center, 20 October, 2006.

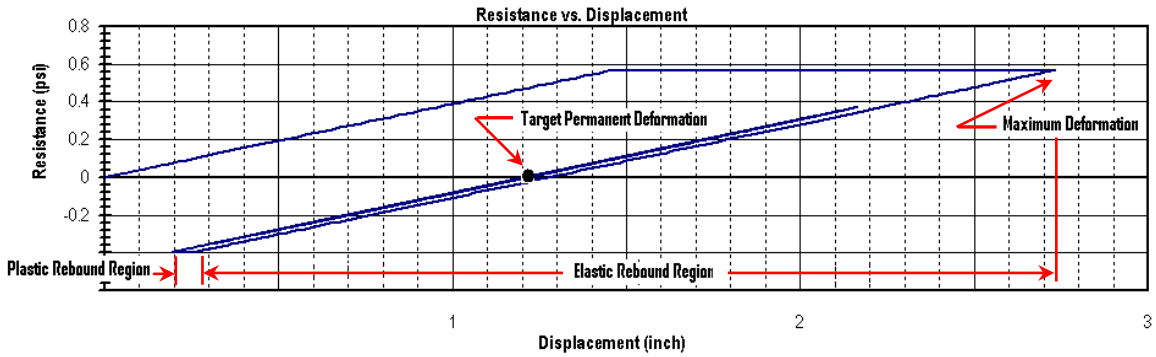


Figure 6. Typical Ductile Resistance-Deflection Curve

3. Results

Figure 7 provides a map of the vicinity surrounding the T2 Laboratories compound as well as a list of buildings surveyed off-site. ABS Consulting surveyed buildings out to a distance where structural damage was no longer observed. This damage extent was approximately 1,750 feet from the explosion source. A total of thirty three (33) buildings were surveyed; buildings included both permanent and portable buildings. A building list with property address and construction type is given in Table 1.

Building #	Property Name	Property Address
100	Stover Sales	3001 Faye Rd
101	Prezine	3041 Faye Rd
200	MastHead	3022 Haye Rd
201	PBM Construction	3000 Faye Rd
201B	PBM Construction	3000 Faye Rd
201C	PBM Construction	3000 Faye Rd
202	Refractory Repair Service	2980 Faye Rd
202B	Refractory Repair Service	2980 Faye Rd
203	Wall Street Trailers	3000-3 Faye Rd
204A	Wall Street Trailers	3000-3 Faye Rd
204B	Wall Street Trailers	3000-3 Faye Rd
300A	Tri-State Contractors	3051 Faye Rd
300B	Tri-State Contractors	3051 Faye Rd
300C	Tri-State Contractors	3051 Faye Rd
301	Cogburn Brothers	3300 Faye Rd
302	Cogburn Brothers	3300 Faye Rd
303	Wilkinson Steel	3210 Faye Rd
304	School bus depot	4000 Faye Rd
304B	School bus depot	4000 Faye Rd
304C	School bus depot	4000 Faye Rd
400	MacCurrach Golf Construction Inc	Faye Rd
401	Personal Residence (same property as 400)	3501 Faye Rd
402	Not Known	3701 Faye Rd
403	Truck Lease Services	3701 Faye Rd
500	Arlington Heavy Hauling	11075 Blasius Rd
501A	Arlington Heavy Hauling	11075 Blasius Rd
501B	Arlington Heavy Hauling	11075 Blasius Rd
502	Arlington Heavy Hauling	11075 Blasius Rd
504	Petticoat Construction Company	11025 Blasius Rd
505	Arlington Heavy Hauling	11075 Blasius Rd
506	Petticoat Construction Company	11025 Blasius Rd
507	Petticoat Construction Company	11025 Blasius Rd

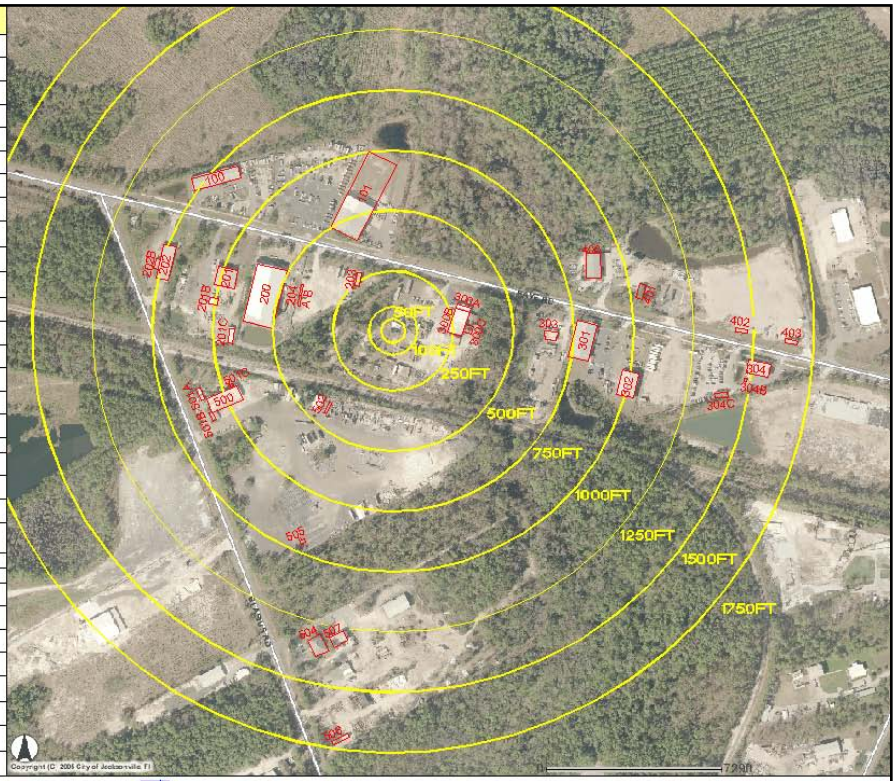


Figure 7. Aerial Site Map of Surveyed Buildings

Table 1. Building List of Off-Site Structures Surveyed

Building Number	Property Name	Property Address	Building Type/Description
100	Stover Sales	3004 Faye Rd	Pre-Engineered metal building.
101	Prezine	3041 Faye Rd	Pre-Engineered metal building.
200	MastHead	3022 Faye Rd	Pre-Engineered metal building.
201	PBM Construction	3000 Faye Rd	Pre-Engineered metal building. CMU wall with brick veneer at north elevation.
201B	PBM Construction	3000 Faye Rd	1-Story wood frame structure with metal wall panels. Wood roof trusses and metal roof panels.
201C	PBM Construction	3000 Faye Rd	Braced steel frames with hot-rolled columns and cold-formed girts and purlins. Metal panel walls and roof.
202	Refractory Repair Service	2980 Faye Rd	Pre-Engineered metal building.
202B	Refractory Repair Service	2980 Faye Rd	Pre-Engineered metal building.
203	Wall Street Trailers	3000-3 Faye Rd	Modular wood trailer
204A	Wall Street Trailers	3000-3 Faye Rd	Steel semi-trailer container.
204B	Wall Street Trailers	3000-3 Faye Rd	Steel semi-trailer container.
300A	Tri-State Contractors	3051 Faye Rd	Pre-Engineered metal building. CMU brick infill on west face.
300B	Tri-State Contractors	3051 Faye Rd	Pre-Engineered metal building.
300C	Tri-State Contractors	3051 Faye Rd	Braced steel frame with cold-formed girts. Steel roof trusses with cold-formed purlins and metal panels. Metal panels erected on west face only.
301	Cogburn Brothers	3300 Faye Rd	Pre-Engineered metal building.
302	Cogburn Brothers	3300 Faye Rd	Pre-Engineered metal building.
303	Wilkinson Steel	3210 Faye Rd	Modular wood trailers, 3 units side-by-side.
304	School Bus Depot	4000 Faye Rd	Pre-Engineered metal building.
304B	School Bus Depot	4000 Faye Rd	Wood frame structure.
304C	School Bus Depot	4000 Faye Rd	Modular wood trailer
400	MacCurrah Golf Construction	3501 Faye Rd	Pre-Engineered metal building.
401	Personal Residence (Trailer)	3501 Faye Rd	Mobile home structure.
402	Not known	3701 Faye Rd	Modular wood trailer
403	Truck Lease Services	3701 Faye Rd	Modular wood trailer
500	Arlington Heavy Hauling	11075 Blasius Rd	Pre-Engineered metal building.
501A	Arlington Heavy Hauling	11075 Blasius Rd	Modular wood trailer
501B	Arlington Heavy Hauling	11075 Blasius Rd	Modular wood trailer
502	Arlington Heavy Hauling	11075 Blasius Rd	Semi-trailer container; aluminum purlins, metal panel walls and roof.
504	Petticoat Construction Company	11025 Blasius Rd	Commercial wood construction.
505	Arlington Heavy Hauling	11075 Blasius Rd	Mobile home structure.
506	Petticoat Construction Company	11025 Blasius Rd	Mobile home structure.
507	Petticoat Construction Company	11025 Blasius Rd	Pre-Engineered metal building.

The estimated TNT yield of the December 19 explosion at T2 Laboratories was obtained by averaging the estimated yields obtained from each data set and was determined to be approximately 1,400 lb_{TNT} as shown below in Table 2. Free field pressure and impulse contours are provided in Figure 8 and Figure 9 respectively.

Table 2. Estimated Yield of T2 Laboratories Explosion

Load Indicator Data Set	Estimated Yield
Structural damaged Load Indicators	1,330 lb_{TNT}
Off-site window breakage	1,506 lb_{TNT}
Average Estimated Yield	1,420 lb_{TNT}

This TNT yield weighed the averages from structural damage and from off-site window damage equally even though the window damage data set had fewer data points than the structural damage data set. However, the two data sets represent different response mechanisms and were therefore analyzed as separate data sets each tending toward an average TNT yield. The structural damage data involves response of unfailed structural components to blast utilizing dynamic nonlinear structural response theory, whereas the window damage data involves failure of brittle glazing and post failure debris throw of fragments. Although the standard deviation of each data set was high, the consistency of the average between the two data sets lends credence to the estimated yield due to the fundamental differences in the response mechanisms of the two data sets and the techniques for their analysis.

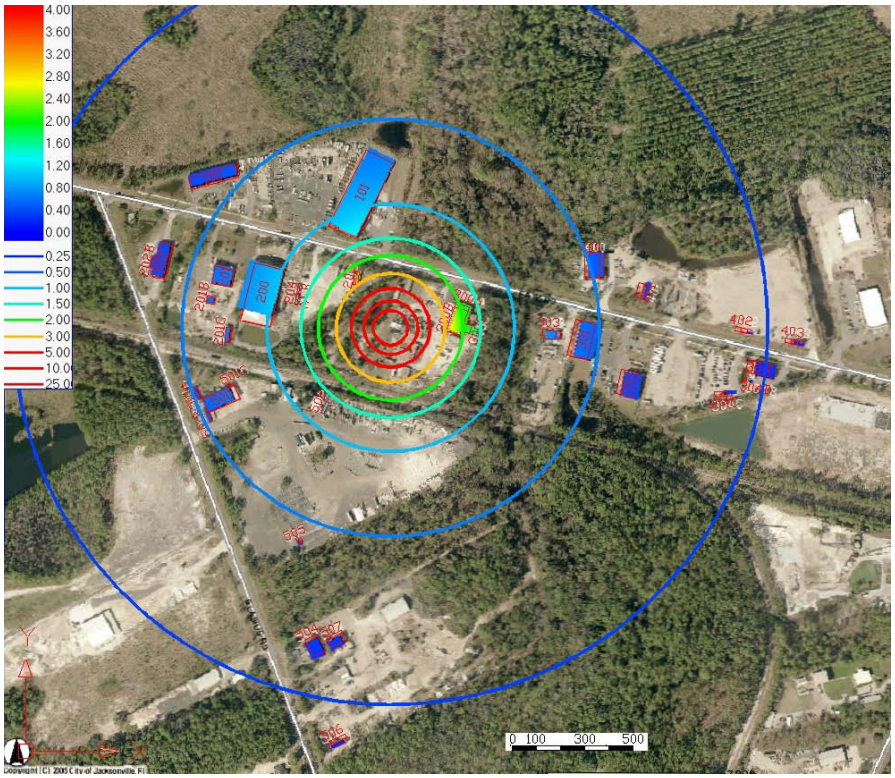


Figure 8. Free-Field Pressure Contours for Estimated TNT Yield of Explosion

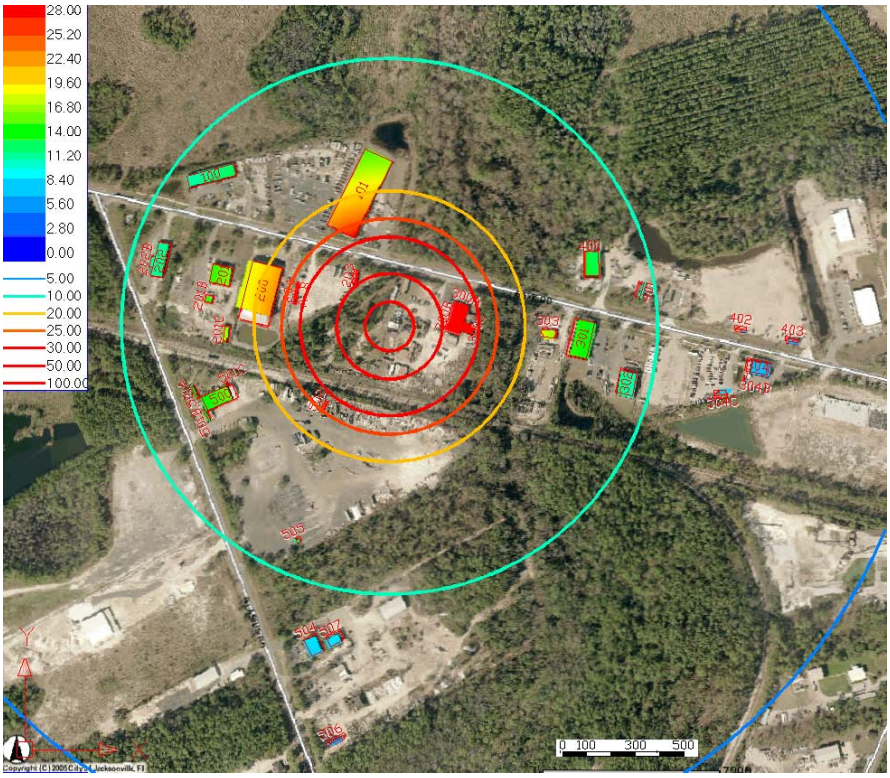


Figure 9. Free-Field Impulse Contours for Estimated TNT Yield of Explosion

4. Injuries and Community Damage

The explosion killed four T2 employees and injured 32 workers at T2 and surrounding businesses. All of the people at T2 during the incident—eight T2 employees and one truck driver making a delivery—were injured or killed. Four T2 employees died of blunt force trauma as a result of the explosion and one was critically injured and hospitalized for several months. The CSB conducted a community survey of the surrounding businesses to characterize injuries and structure damage (Figure 10). At the nine businesses within 1,900 feet of the reactor, the explosion injured 27 workers. Of those, 11 suffered lacerations and contusions, seven reported hearing loss, and five fell or were thrown by the force of the blast. A summary of the injury and fatality statistics are provided in Table 3 and details of the injuries as recorded by the CSB are provided in Table 4.

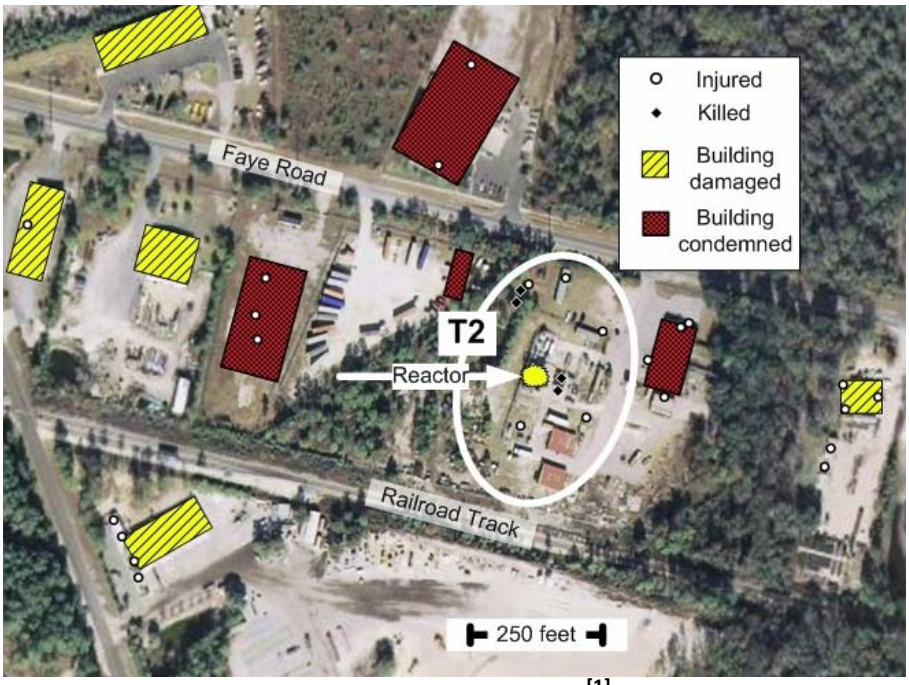


Figure 10. Injury Map[1]

A summary of the injury statistics is presented in Table 3. Four T2 Laboratories personnel were fatally injured as a result of the explosion. Notably, two of the fatalities occurred inside of the masonry Control Room.

Table 3. Personnel Injury Statistics[1]

Business Name	K-factor	Number of Employees Present	Number of Non-Fatally Injured	Number of Fatally Injured
T2 Laboratories	0	8	4	4
Linden Bulk Transfer (Driver)	0	1	1	0
TriState Contractors	K25	13	4	0
Wall Street Trucking*	K25	0		
Prezine, LLC	K50	18	6	0
Masthead Hose	K50	7	3	0
Wilkinson Steel Co.	K58	16	8	0
Arlington Hauling	K60 – K75	17	4	0
PBM Constructors	K65	3	0	0
Cogburn Brothers	K70	12	0	0
MacCurrach Golf	K78	4	0	0
Stovers Trucking	K86	20	0	0
Refractory Repair	K88	3	1	0
Petticoat Contracting	K120	13	0	0
First Student Bus	K136	7	0	0
Milton J Wood		25	1	0
Westside Electric		23	0	0
Totals		190	32	4

Notes: *Employees left early due to holiday

Table 4. Detailed Personnel Injury Records

Business	Nature of Injury	Location at TOI
T2 Laboratories	Fatality (F1)	Plant Control Room
T2 Laboratories	Fatality (F2)	Plant Control Room
T2 Laboratories	Fatality (F3)	NW Corner of Plant
T2 Laboratories	Fatality (F4)	NW Corner of Plant
T2 Laboratories	Received stitches to head, shoulder bruise and scratches to head	Was in office trailer at N.W. corner of plant
T2 Laboratories	Critically injured admitted to Shands Hospital	Was last seen standing with F3 and F4 at TOI in N.W. corner of plant.
T2 Laboratories	Received possible sodium burns to scalp, heat flash injuries.	Near T-2 Reactor, to the South
T2 Laboratories	Heart attack, rendered unconscious briefly. Hospitalized.	Near roll-off dumpster near shipping containers
Milton J Wood Consolidated	Suffered abrasions and contusions to back and neck. Was transported to hospital in ambulance and was treated and released within 5 hours.	Office
Linden Bulk Transfer	Ear ringing/popping, eyes (scratched cornea from shard of glass), superficial cuts on face, right side stiff, pain in back, pieces of glass in leg.	Was offloading 141 mineral spirits from tanker truck
Prezine	Cut in head, went to triage location and was then transported to hospital in ambulance - no lost time	inside warehouse
Prezine	De-conned from exposure to dust, transported and released	Was in Prezine warehouse
Prezine	Cut by shards of glass when an overhead light fell. Taken by ambulance to the hospital, treated and de-conned - no lost time	Was in Prezine warehouse
Refractory Repair Service (Owner)	Two hearing aids damaged, small cuts on face and hand from Plexiglas. Small cut on thumb. Bridge work to tooth may have been damaged. Possible mild concussion from hitting bathroom door with head.	
Masthead Hose Supply	High blood pressure, contusions, bruised lungs and pectoral area.	
Masthead Hose Supply	Bump on head, contusion to knee, ringing in ears.	
Masthead Hose Supply	Ringing in ears, sharp pain in ears.	
Arlington Heavy Hauling	Cuts to forehead, cheek, high blood pressure (179), bleeding nose, admitted due to pre-existing heart issues.	Was in trailer office southwest of T-2 facility
Arlington Heavy Hauling	Cuts to face, neck, shoulder, hand (2 cuts), arms contusion to chest and neck ache. Self-transported to Solantic Urgent Care for treatment. Was not admitted.	Was in trailer office southwest of T-2 facility
Arlington Heavy Hauling	Several glass cuts on forehead, arms, shoulder, back and to scalp.	Was in trailer office southwest of T-2 facility
Arlington Heavy Hauling	Fracture of knee-cap, chip to other knee-cap. Went to Solantic Urgent Care for treatment. Was not admitted.	Was in trailer office southwest of T-2 facility
Wilkinson Steel Company, Inc..	Right ankle sprain and headache	No employees were taken to hospital in ambulance. Sought medical attention separately.
Wilkinson Steel Company, Inc..	Both wrists sprained, lost hearing in left ear	
Wilkinson Steel Company, Inc..	Neck and back sprain, headache, bruised left forearm, jammed finger, x-rays taken at hospital.	
Wilkinson Steel Company, Inc..	Low back pain, earache, headache	

Business	Nature of Injury	Location at TOI
Wilkinson Steel Company, Inc..	Pain in right shoulder (No treatment)	
Wilkinson Steel Company, Inc..	Anxiety attack, scratched left forearm	
Wilkinson Steel Company, Inc..	Eyes and throat burning, sprained neck and back.	
Wilkinson Steel Company, Inc..	Shard of glass in throat	
Tristate Contractors	Bruised shoulder - sought medical attention as a precaution	Was standing next to forklift outside of rollup door at Tristate
Tristate Contractors	Perforated ear drum - currently on medication	Was standing in the front entrance of Tristate when the explosion took place
Tristate Contractors	Hit with debris in the back of the thigh, muscle swelled and moved to calf	Was standing in break area behind Tristate
Tristate Contractors	Shards of glass in arm, shoulder, back of head, dislocated ribs (4),strained wrist, fractured tail-bone	Was sitting at desk in office

5. Off-Site Building Damage Observations

Qualitative building damage levels were assigned to all buildings surveyed based on damage descriptions from the Explosive Risk and Structural Damage Assessment Code (ERASDAC)[6] and from the SDOF Blast Effects Design Spreadsheet (SBEDS)[5] computer program. Building damage descriptions for both ERASDAC and SBEDS are given in Table 5 and Table 6, respectively.

The approach for defining building damage used by the two programs differs. SBEDS bases the overall building damage levels on the worst damaged component in the given building. No distinction is given to component location (i.e. reflected versus side-on); however, damage to primary members is weighted more heavily in determining the overall building damage than damage to secondary members. ERASDAC's building damage descriptions are based on a component damage matrix consisting of reflected wall component damage, side-on wall component damage and roof component damage. The latter approach could be more representative of damage to the overall structural system, while SBEDS' approach may be indicative of localized damage.

Building damage levels were assigned to each building based on observed and measured damage and are summarized in Table 7. A graphical map showing ERASCAC and SBEDS qualitative building damage levels is given in Figure 11 and Figure 12, respectively. Side walls and back walls which were significantly deformed outward due to blast loads entering the building envelope through large roll-up doors were not considered in evaluating building damage levels. This is because the methodologies utilized are for assessing buildings subjected to external blast loading. Inspection of Table 7 shows that

[6] Oswald, Charles J. "Vulnerability Model for Occupants of Blast Damaged Buildings", 34th Annual Loss Prevention Symposium, Session 3, November 6, 1999.

the potential exists to cause structural damage well beyond K40 separation. Two large pre-engineered warehouses (Buildings 101 and 200) located at K50 were condemned as a result of the explosion.

Table 5. ERASDAC Building Damage Level Description[6]

Building Damage Level	Damage Description
1	Onset of visible damage to reflected wall of building.
2.0 (2A)	Reflected wall components sustain permanent damage requiring replacement, other walls and roof have visible damage that is generally repairable.
2.5 (2B)	Reflected wall components are collapsed or very severely damaged. Other walls and roof have permanent damage requiring replacement.
3	Reflected wall has collapsed. Other walls and roof have substantial plastic deformation that may be approaching incipient collapse.
4	Complete failure of the building roof and substantial area of walls.

Table 6. SBEDS Building Damage Level Description[5]

Building Damage Level	Damage Description
Superficial Damage	No permanent deformations. The facility is immediately operable.
Repairable Damage	Space in and around damaged area can be used and is fully functional after cleanup and repairs.
Unrepairable Damage	Progressive collapse will not occur. Space in and around the damaged area is unusable.
Heavy Damage	Onset of structural collapse. Progressive collapse is unlikely. Space in and around damaged area is unusable.
Severe Damage	Progressive collapse likely. Space in and around damaged area is unusable.

Table 7. Summary of Observed Building Damage Levels

Building #	Standoff	K-factor	ERASDAC BDL	SBEDS BDL
100	970 ft.	86	1*	Superficial*
101	570 ft.	51	2A*	Unrepairable*
200	550 ft	49	2A*	Unrepairable*
201	730 ft.	65	2A	Repairable
201B	760 ft.	67	2A	Repairable
201C	670 ft.	60	2A	Repairable
202	990 ft.	88	2A	Repairable
202B	1,020 ft.	91	1	Superficial
203	260 ft.	23	2B	Heavy
204A	410 ft.	36	2A	Unrepairable
204B	420 ft.	37	2A	Unrepairable
300A	310 ft.	27	2A	Unrepairable
300B	280 ft.	25	3	Heavy
300C	310 ft.	28	2A	Repairable
301	790 ft.	70	2A	Repairable
302	1,000 ft.	89	1	Superficial
303	660 ft.	58	1	Superficial
304	1,530 ft.	136	1	Superficial
304B	1,480 ft.	132	1	Superficial
304C	1, 390 ft	124	1	Superficial
400	880 ft.	78	2A	Repairable
401	1,040 ft.	93	1	Superficial
402	1, 450 ft.	129	1	Superficial
403	1,660 ft.	148	1	Superficial
500	760 ft.	67	1*	Superficial*
501A	840 ft.	75	1	Superficial
501B	830 ft.	74	1	Superficial
501C	710 ft.	63	2A	Repairable
502	420 ft.	37	2A	Unrepairable
504	1,340 ft.	119	1	Superficial
505	950 ft.	85	1	Superficial
506	1,700 ft.	152	1	Superficial
507	1,300 ft.	116	1	Superficial

1. *Back and/or side walls sustained damage from internal load penetrating the building though open roll-up doors.
2. Note: Standoff distance were measured to the center of the building roof, not to the nearest point in the building as would typically be performed for quantity-distance relationships

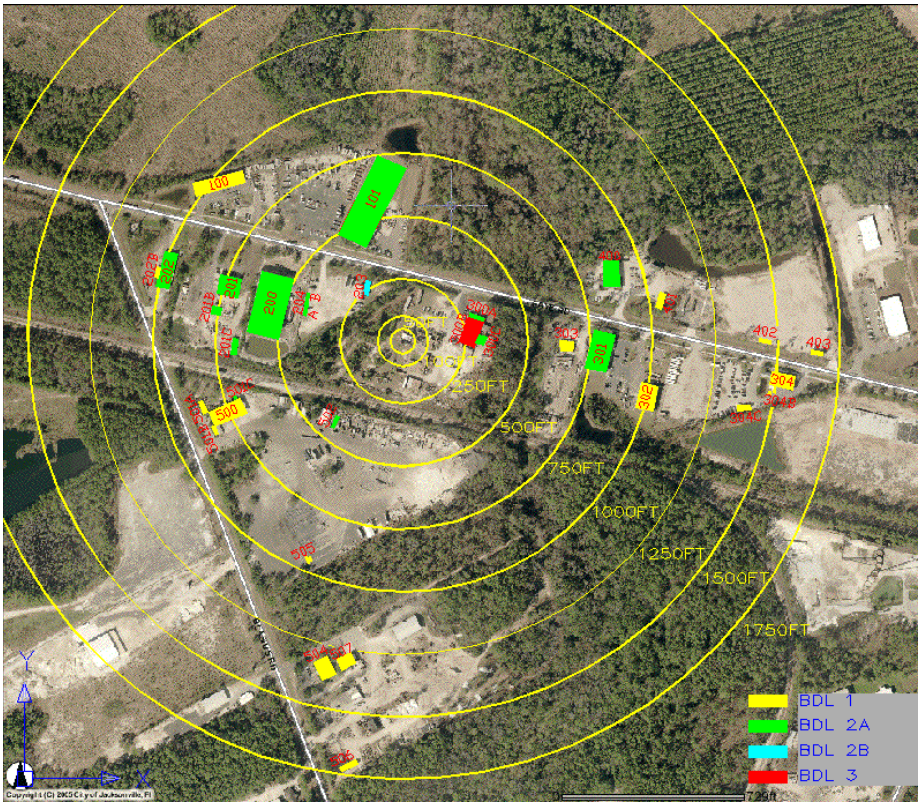


Figure 11. Map of ERASDAC Qualitative Building Damage

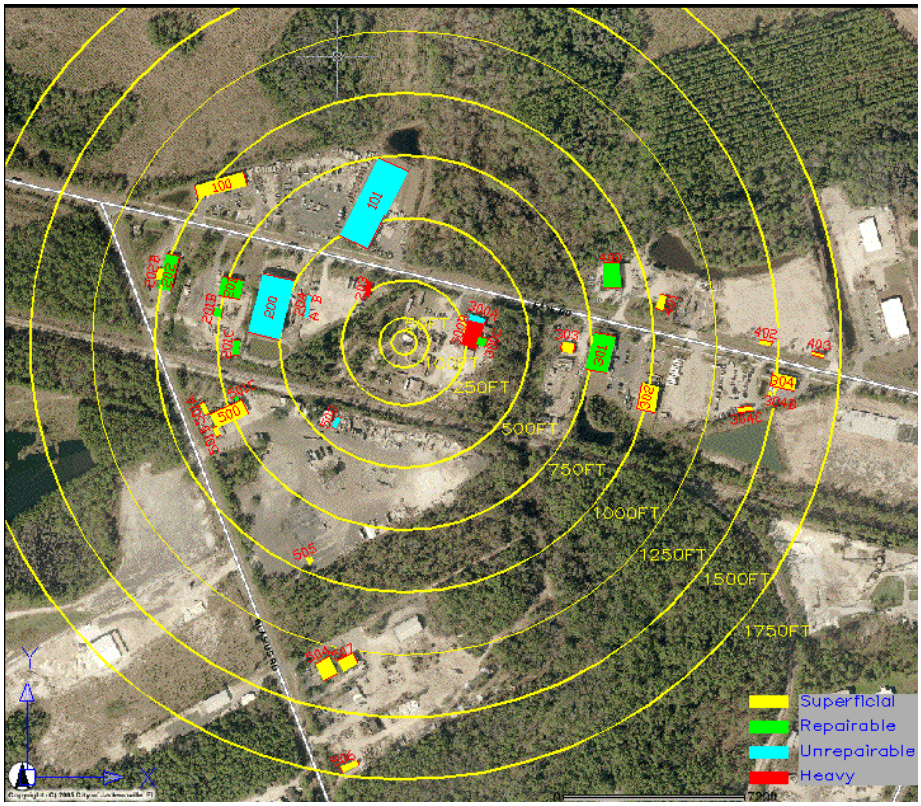


Figure 12. Map of SBEDS Qualitative Building Damage

5.1. Window Damage Observations

ABS Consulting surveyed windows which broke in the incident up to the structural damage extent at 1,750 feet. A map detailing buildings with observed window breakage is shown below in Figure 13.

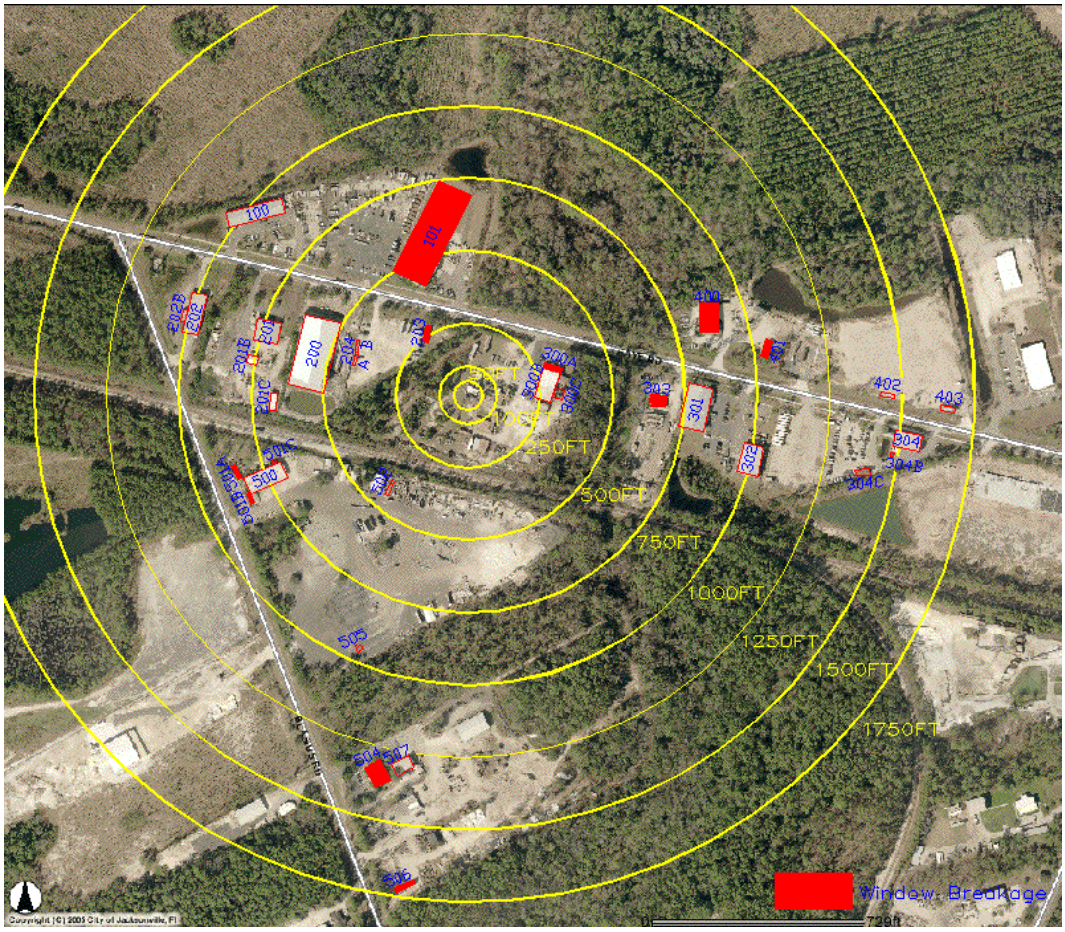


Figure 13. Map of Off-Site Window Breakage

Fragment travel of broken glazing is used to quantify the window performance condition in accordance with the Interagency Security Committee (ISC) criteria[7] which have been adopted by the General Services Administration (GSA) and implemented in the computer software WINGARD (Window Glazing Analysis Response and Design)[8]. ISC glazing performance conditions are described for each hazard condition in Table 8. Table 9 details the maximum hazard level observed for each building with windows. In many instances the windows had been repaired or replaced prior to inspection by ABS Consulting; however, occupants testified to which windows had broken and the extent of the window fragment travel. Table 9 shows that high hazard level (Level 5) was observed at K50, Medium Hazard Level (Level 4) was observed at up to K75 and that window damage was observed at over K100.

[7] ISC Security Design Criteria for New Federal Office Buildings and Major Modernization Projects, Interagency Security Committee, 2001.

[8] Window Glazing Analysis Response and Design Multi-Pane (WINGARD MP), Applied Research Associates, Inc., September 2006.

Table 8. Glazing Protection Levels Based on Fragment Impact Locations[8]

Performance Condition	Protection Level	Hazard Level	Description of Window Glazing Response
1	Safe	None	Glazing does not break. No visible damage to glazing or frame.
2	Very High	None	Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.
3a	High	Very Low	Glazing cracks. Fragments enter space and land on floor no further than 3.3 ft. from the window.
3b	High	Low	Glazing cracks. Fragments enter space and land on floor no further than 10 ft. from the window.
4	Medium	Medium	Glazing cracks. Fragments enter space and land on floor and impact a vertical witness panel at a distance no more than 10 ft. from the window at a height no greater than 2 ft. above the floor.
5	Low	High	Glazing cracks and window system fails catastrophically. Fragments enter a space bounded by a vertical witness panel located at a distance of 10 ft. from the window and extending above a height of 2 ft. above the floor.

A summary of building number, standoff distance, window description, and observed performance condition is given below in Table 9.

Table 9. Observed Window Damage and Fragment Performance Condition

Building #	Standoff (ft)	K-factor	Highest Hazard Level
101	570 ft.	51	5
203	260 ft.	23	5
300A	310 ft.	27	5
301	790 ft.	70	1
302	1,000 ft.	89	1
303	660 ft.	58	3-4
400	880 ft.	78	4
401	1,040 ft.	93	3b
501A	840 ft.	75	4
501B	830 ft.	74	4
504	1,340 ft.	119	*Note
506	1,700 ft.	152	*Note

**Note: Window breakage was reported by owners but had been repaired prior to inspection. No hazard level could be determined.*

6. Conclusion

ABSG Consulting Inc. (ABS Consulting) was contracted by the U.S. Chemical Safety Board (CSB) to 1) conduct a site survey to document blast related structural damage, 2) perform analysis to estimate explosion energy, and 3) develop overpressure and impulse contour maps for the T2 Laboratories Inc. in Jacksonville, Florida. The explosion energy was determined to be equivalent to approximately 1,400 lb_{TNT}. The following observations were made pertaining to building damage and window hazards:

1. K50
    a. Two pre-engineered metal buildings were condemned
    b. High Hazard glass fragment throw (Level 5)
2. K75
    a. Repairable damage to pre-engineered buildings
    b. Medium Hazard fragment throw (Level 4)

In addition window breakage and injury were recorded at distances of K75 which is well in excess of K40 or incremental IBD. The T2 explosion shows that the potential exists to cause damage to structures and businesses as well as injury well outside of K40 separation and highlights the need to continue to investigate explosions and understand their consequences.

T2 Laboratories Explosion Damage Assessment

Presented by:
Ben F. Harrison, P.E.

Co Authors:
Sanaa Alaoui, P.E. – ABS Consulting
Robert Hall, P.E. – Chemical Safety Board

Background

- T2 Laboratories Explosion
  - December 19, 2007 at 1:30pm

Explosion Source

Background

Control Building

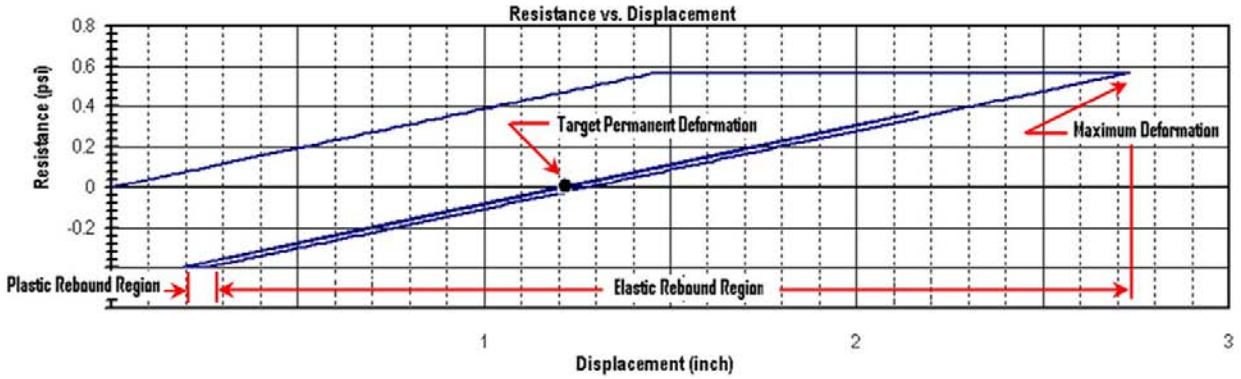
Reactor Pad

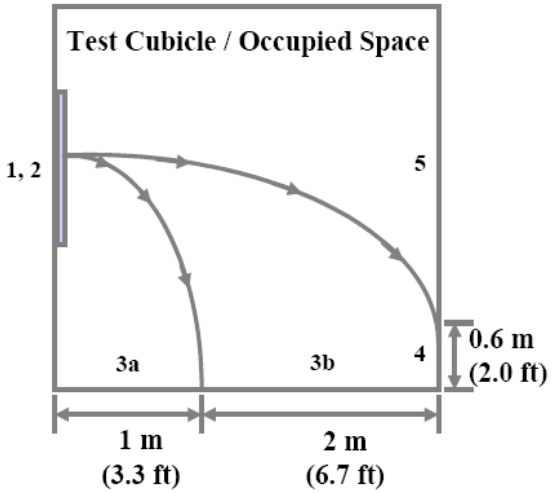
Investigation

- Support CSB Root Cause Investigation
  - Survey of Structural Damage
  - Perform an Estimate of Explosion Energy
  - Develop Overpressure and Impulse Contours

Methodology

- Measure Damage and Undamaged Load Indicators
  - Structural Components
  - Window Glass Fragment Hazards

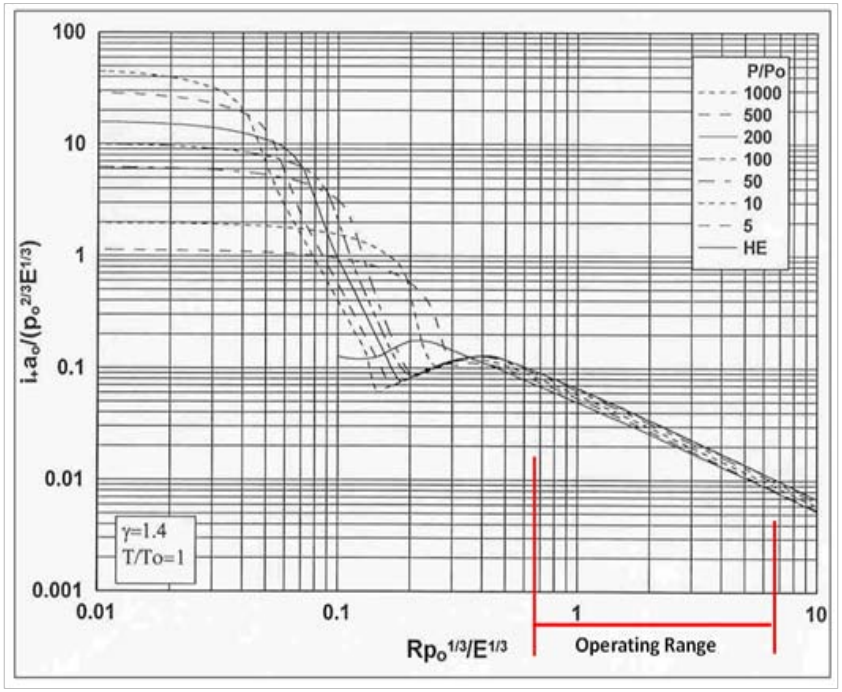


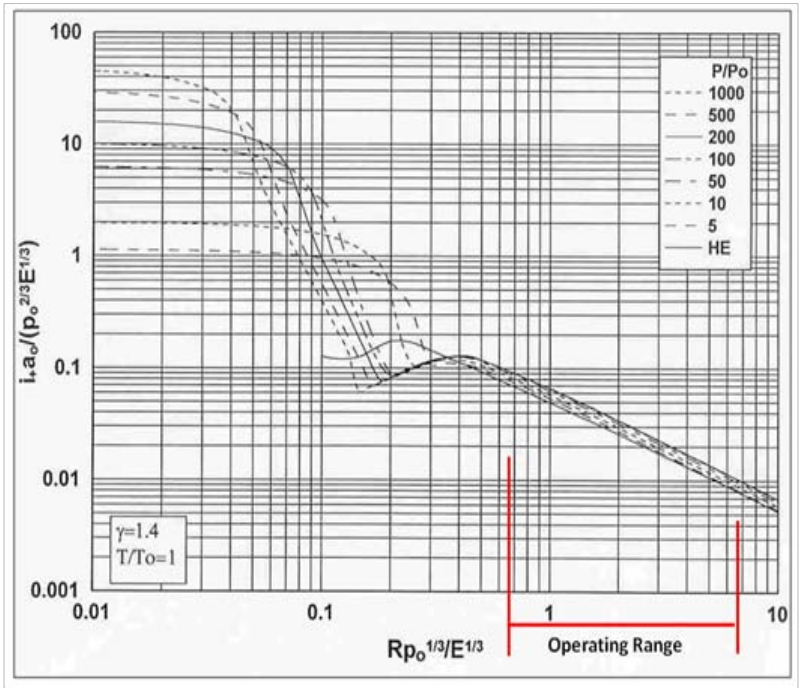


Methodology

- Use Equivalent TNT Based on Pressure Vessel Burst Curves for Applicable Rbar

$$Rbar = Rp_0^{1/3} / E^{1/3}$$





Surveyed Buildings

Building #	Property Name	Property Address
100	Stover Sales	3001 Faye Rd
101	Prezine	3041 Faye Rd
200	MastHead	3022 Haye Rd
201	PBM Construction	3000 Faye Rd
201B	PBM Construction	3000 Faye Rd
201C	PBM Construction	3000 Faye Rd
202	Refractory Repair Service	2980 Faye Rd
202B	Refractory Repair Service	2980 Faye Rd
203	Wall Street Trailers	3000-3 Faye Rd
204A	Wall Street Trailers	3000-3 Faye Rd
204B	Wall Street Trailers	3000-3 Faye Rd
300A	Tri-State Contractors	3051 Faye Rd
300B	Tri-State Contractors	3051 Faye Rd
300C	Tri-State Contractors	3051 Faye Rd
301	Cogburn Brothers	3300 Faye Rd
302	Cogburn Brothers	3300 Faye Rd
303	Wilkinson Steel	3210 Faye Rd
304	School bus depot	4000 Faye Rd
304B	School bus depot	4000 Faye Rd
304C	School bus depot	4000 Faye Rd
400	MacCurrach Golf Construction Inc	Faye Rd
401	Personal Residence (same property as 400)	3501 Faye Rd
402	Not Known	3701 Faye Rd
403	Truck Lease Services	3701 Faye Rd
500	Arlington Heavy Hauling	11075 Blasius Rd
501A	Arlington Heavy Hauling	11075 Blasius Rd
501B	Arlington Heavy Hauling	11075 Blasius Rd
502	Arlington Heavy Hauling	11075 Blasius Rd
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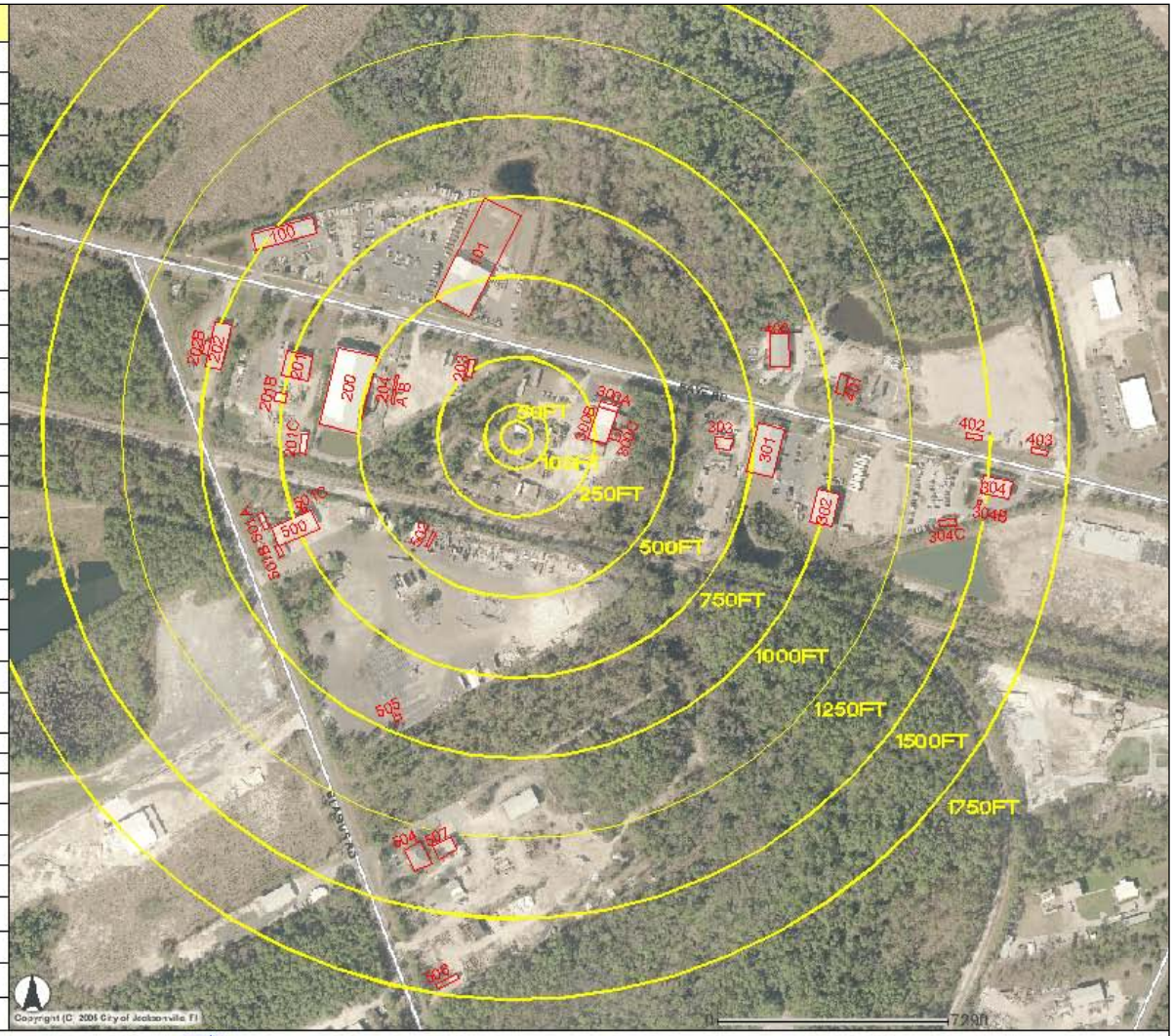

ABS Consulting

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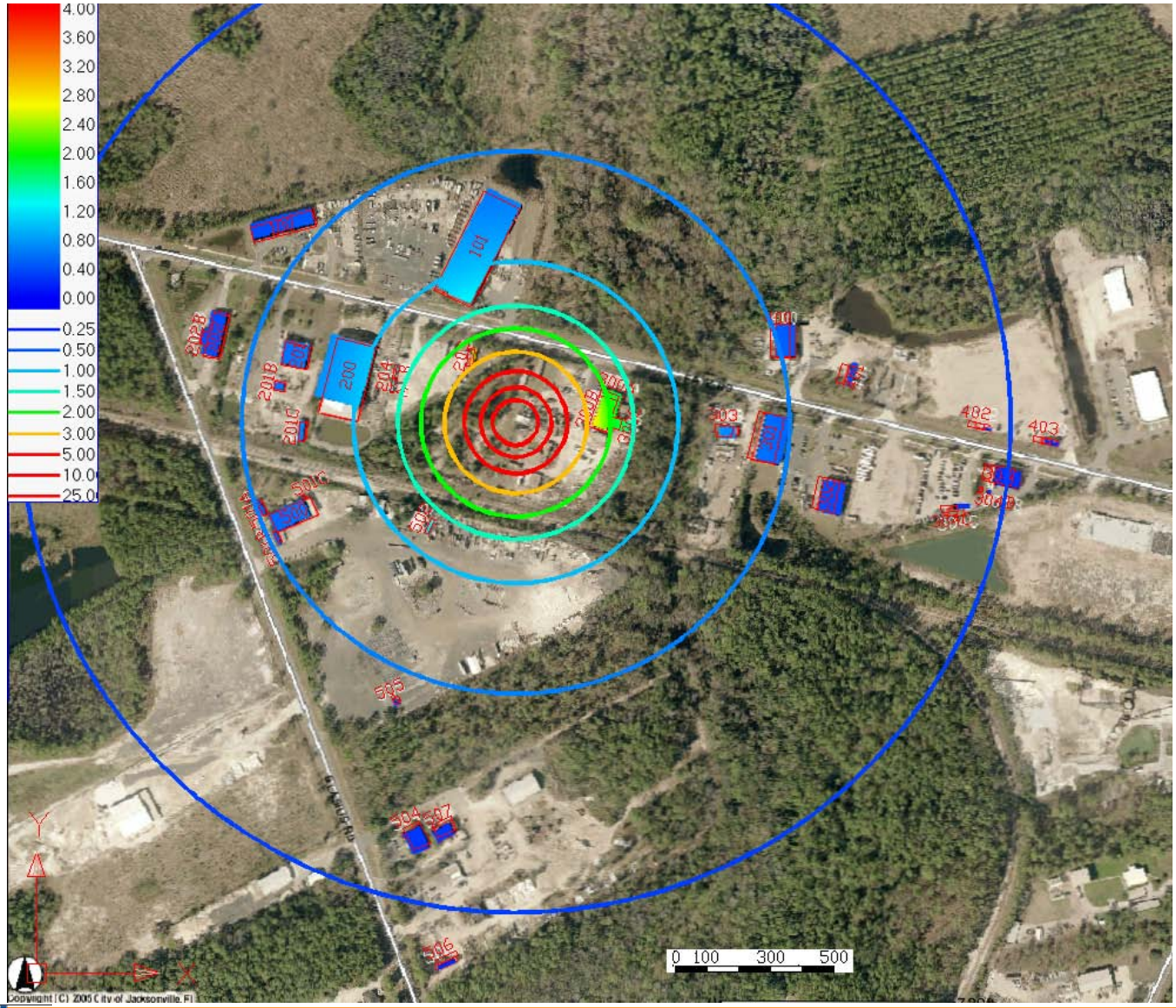
T2 Laboratories Explosion Incident
Off Site Building Damage Survey

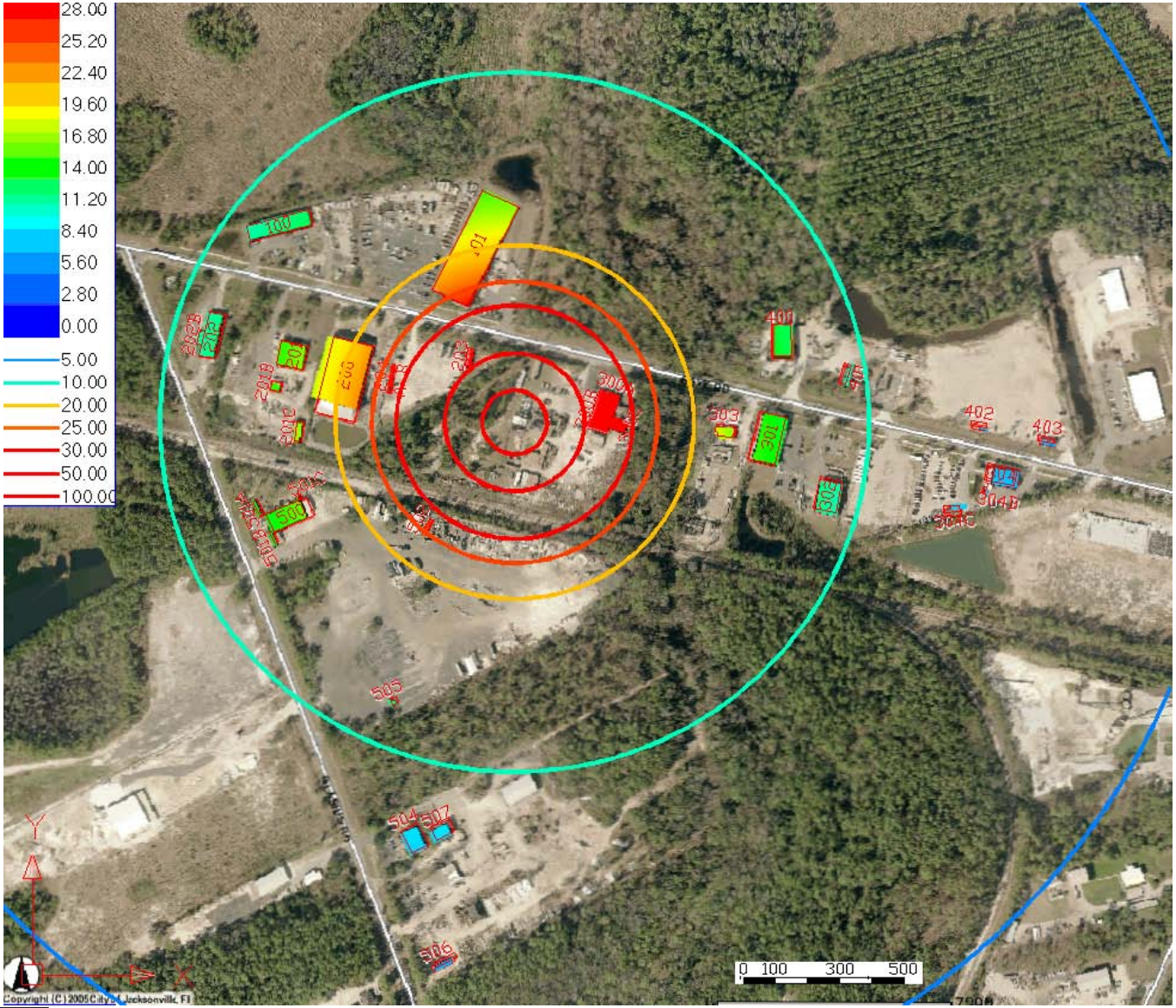
Estimated Yield – 1,400 lb_{TNT}

- Structural Damage Indicators – ~1,300 lb_{TNT}
- Window Fragment Hazards – ~1,500 lb_{TNT}

Pressure Contours

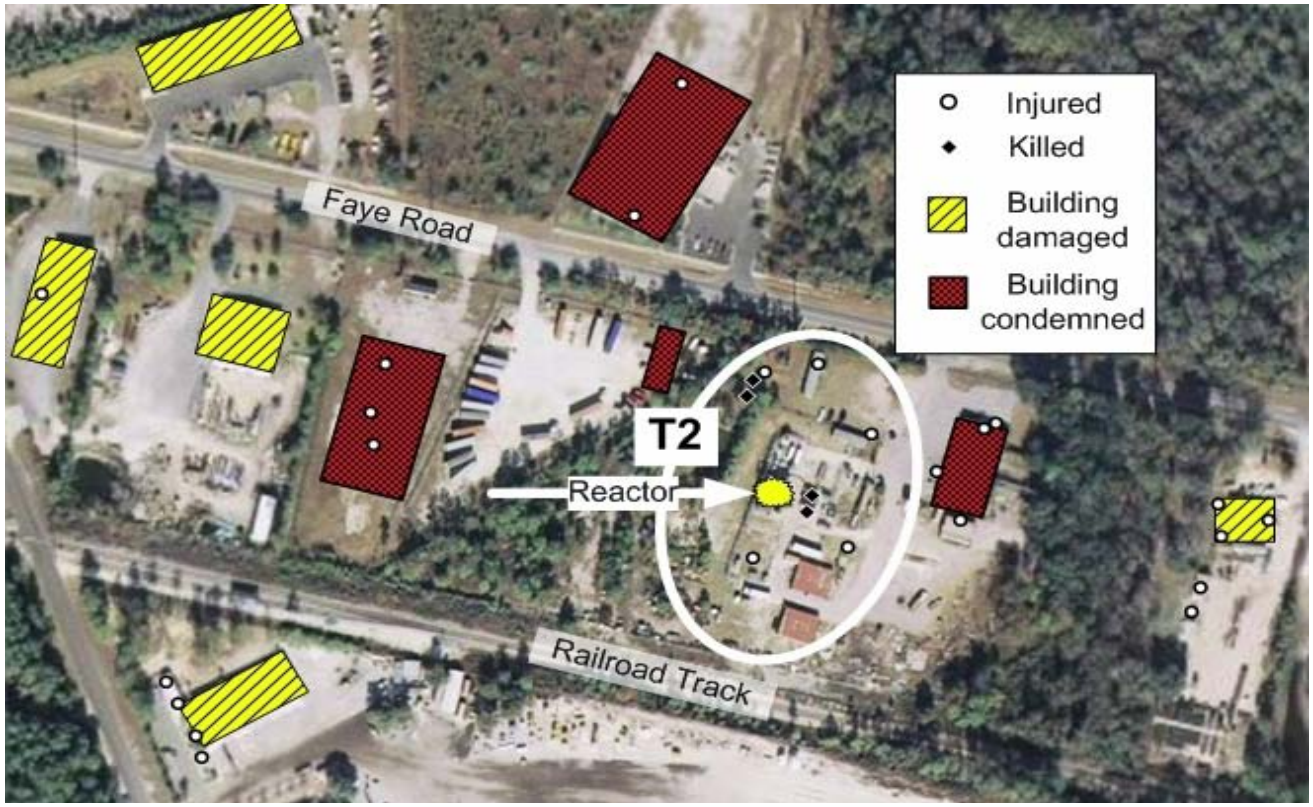


Impulse Contours



Injury Summary

- T2 Laboratories
  - 4 Fatalities
  - 4 Injures (1 Critical)
- Off-Site Businesses
  - 28 Injuries



Notes: *Employees left early due to holiday

Personal Injury Statistics

Business Name	K-factor	Number of Employees Present	Number of Non-Fatally Injured	Number of Fatally Injured
T2 Laboratories	0	8	4	4
Linden Bulk Transfer (Driver)	0	1	1	0
TriState Contractors	K25	13	4	0
Wall Street Trucking*	K25	0		
Prezine, LLC	K50	18	6	0
Masthead Hose	K50	7	3	0
Wilkinson Steel Co.	K58	16	8	0
Arlington Hauling	K60 – K75	17	4	0
PBM Constructors	K65	3	0	0
Cogburn Brothers	K70	12	0	0
MacCurrach Golf	K78	4	0	0
Stovers Trucking	K86	20	0	0
Refractory Repair	K88	3	1	0
Petticoat Contracting	K120	13	0	0
First Student Bus	K136	7	0	0
Milton J Wood		25	1	0
Westside Electric		23	0	0
Totals		190	32	4

Example Building Damage Building 300 (K25)

Building #	Property Name	Property Address
100	Stover Sales	3001 Faye Rd
101	Prezine	3041 Faye Rd
200	MastHead	3022 Haye Rd
201	PBM Construction	3000 Faye Rd
201B	PBM Construction	3000 Faye Rd
201C	PBM Construction	3000 Faye Rd
202	Refractory Repair Service	2980 Faye Rd
202B	Refractory Repair Service	2980 Faye Rd
203	Wall Street Trailers	3000-3 Faye Rd
204A	Wall Street Trailers	3000-3 Faye Rd
204B	Wall Street Trailers	3000-3 Faye Rd
300A	Tri-State Contractors	3051 Faye Rd
300B	Tri-State Contractors	3051 Faye Rd
300C	Tri-State Contractors	3051 Faye Rd
301	Cogburn Brothers	3300 Faye Rd
302	Cogburn Brothers	3300 Faye Rd
303	Wilkinson Steel	3210 Faye Rd
304	School bus depot	4000 Faye Rd
304B	School bus depot	4000 Faye Rd
304C	School bus depot	4000 Faye Rd
400	MacCurrach Golf Construction Inc	Faye Rd
401	Personal Residence (same property as 400)	3501 Faye Rd
402	Not Known	3701 Faye Rd
403	Truck Lease Services	3701 Faye Rd
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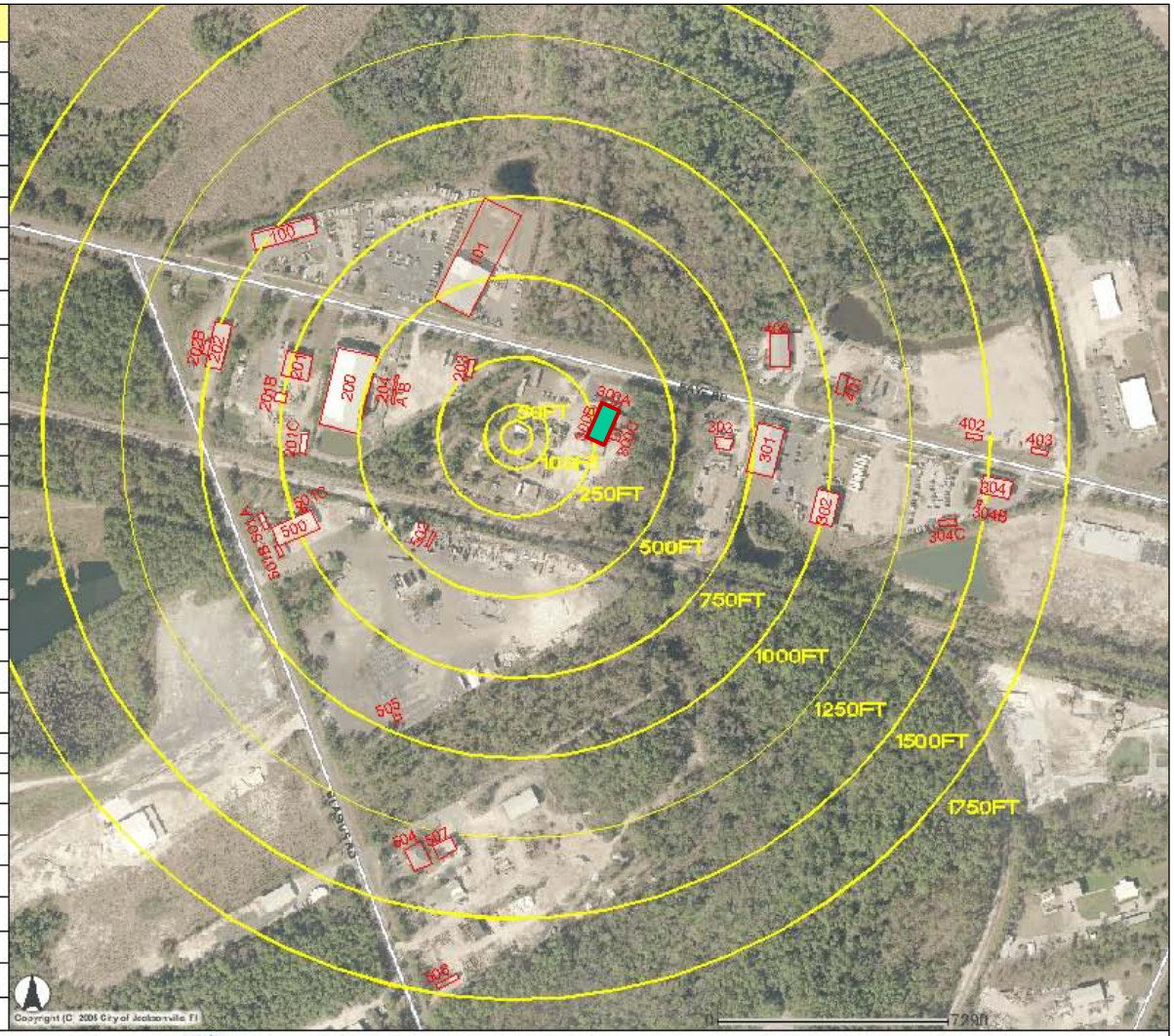

ABS Consulting

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T2 Laboratories Explosion Incident
Off Site Building Damage Survey

Building 300 – K25

- ERASDAC BDL 3
- SBEDS Heavy Damage

Example Building Damage Building 200 (K50)

Building #	Property Name	Property Address
100	Stover Sales	3001 Faye Rd
101	Prezine	3041 Faye Rd
200	MastHead	3022 Haye Rd
201	PBM Construction	3000 Faye Rd
201B	PBM Construction	3000 Faye Rd
201C	PBM Construction	3000 Faye Rd
202	Refractory Repair Service	2980 Faye Rd
202B	Refractory Repair Service	2980 Faye Rd
203	Wall Street Trailers	3000-3 Faye Rd
204A	Wall Street Trailers	3000-3 Faye Rd
204B	Wall Street Trailers	3000-3 Faye Rd
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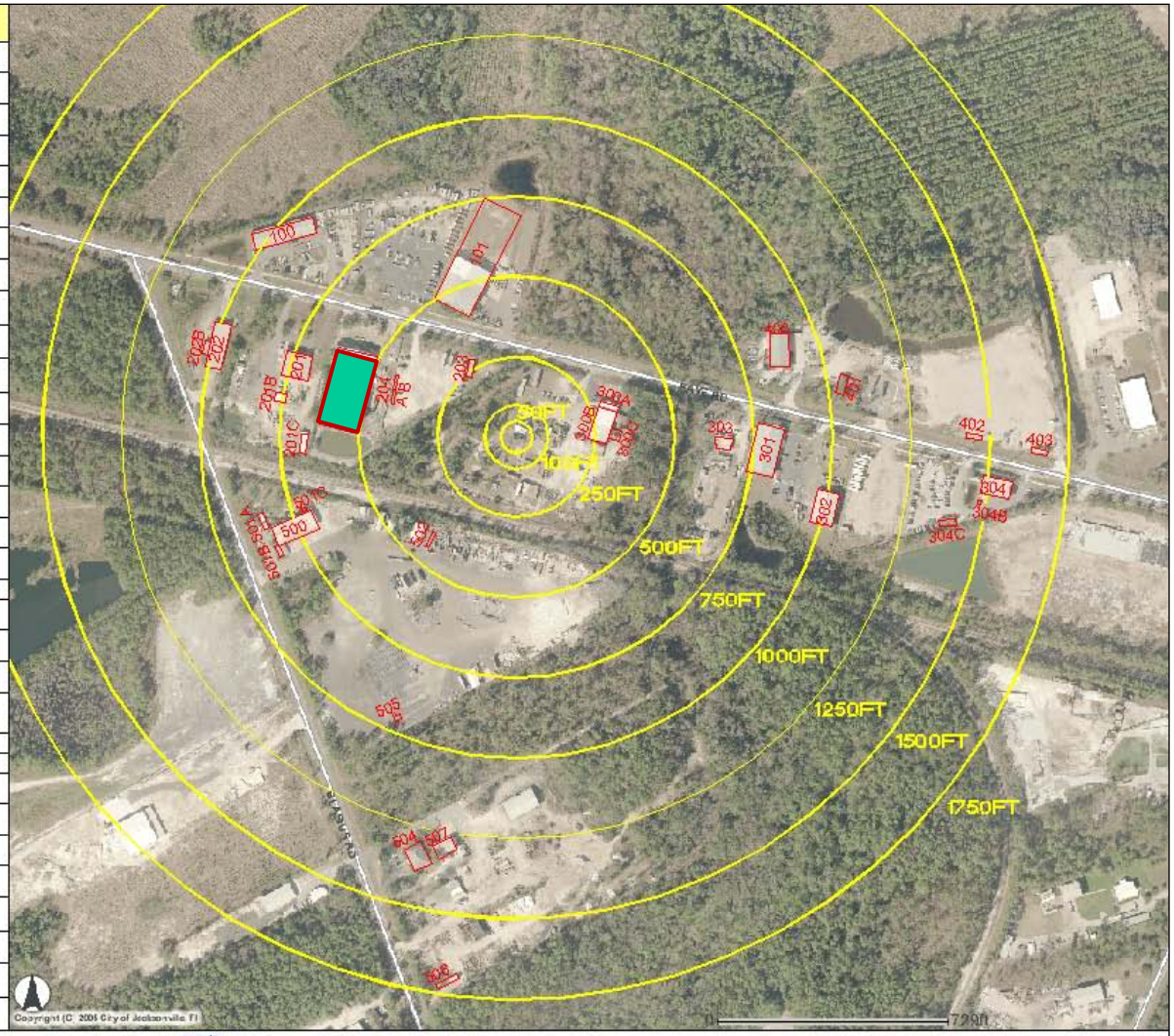

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T2 Laboratories Explosion Incident
Off Site Building Damage Survey

Building 200 – K50

- ERASDAC BDL 2A
- SBEDS Unrepairable

Example Window Damage Building 101 (K50)

Building #	Property Name	Property Address
100	Stover Sales	3001 Faye Rd
101	Prezine	3041 Faye Rd
200	MastHead	3022 Haye Rd
201	PBM Construction	3000 Faye Rd
201B	PBM Construction	3000 Faye Rd
201C	PBM Construction	3000 Faye Rd
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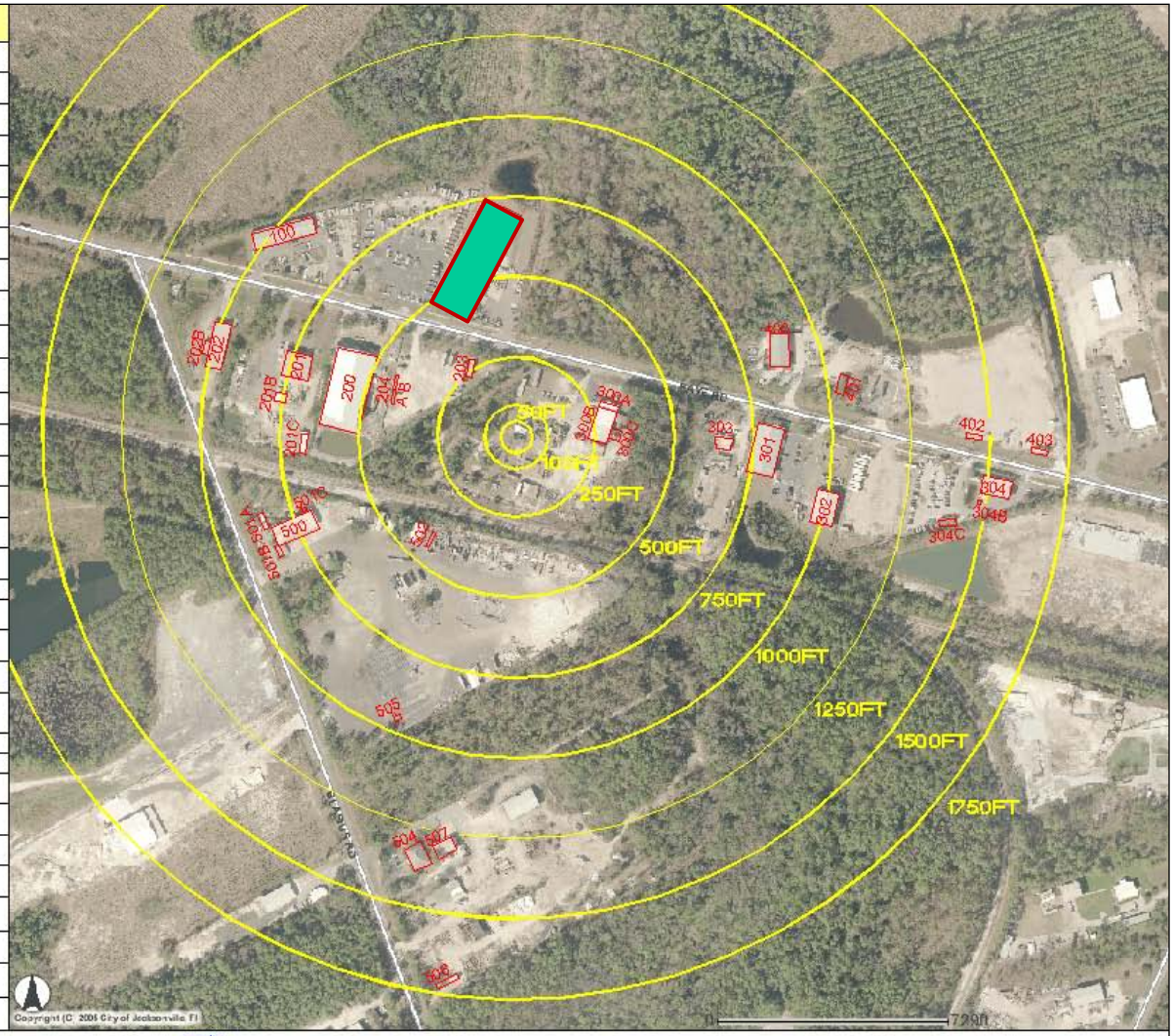

ABS Consulting

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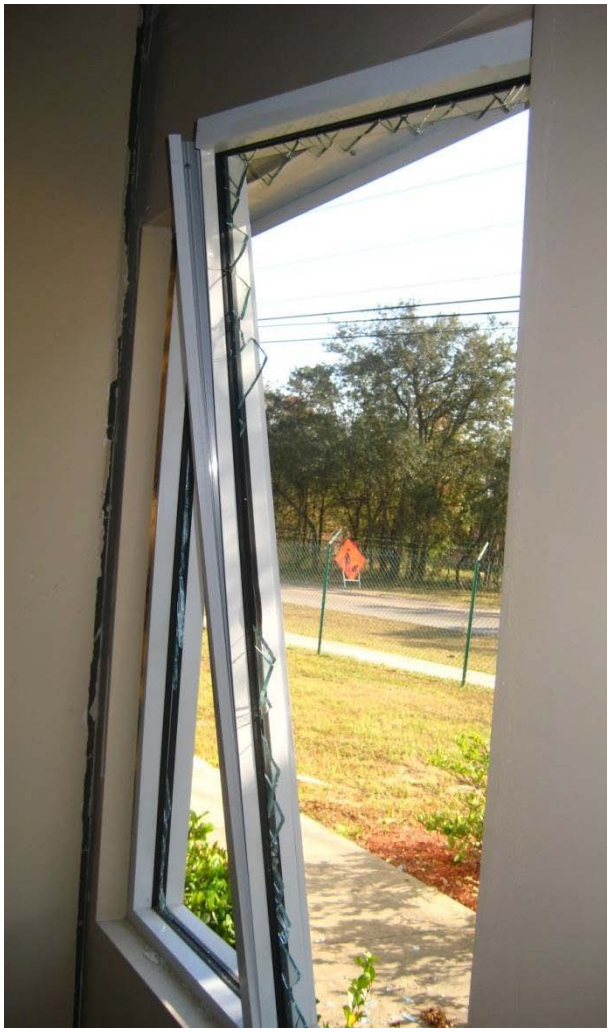
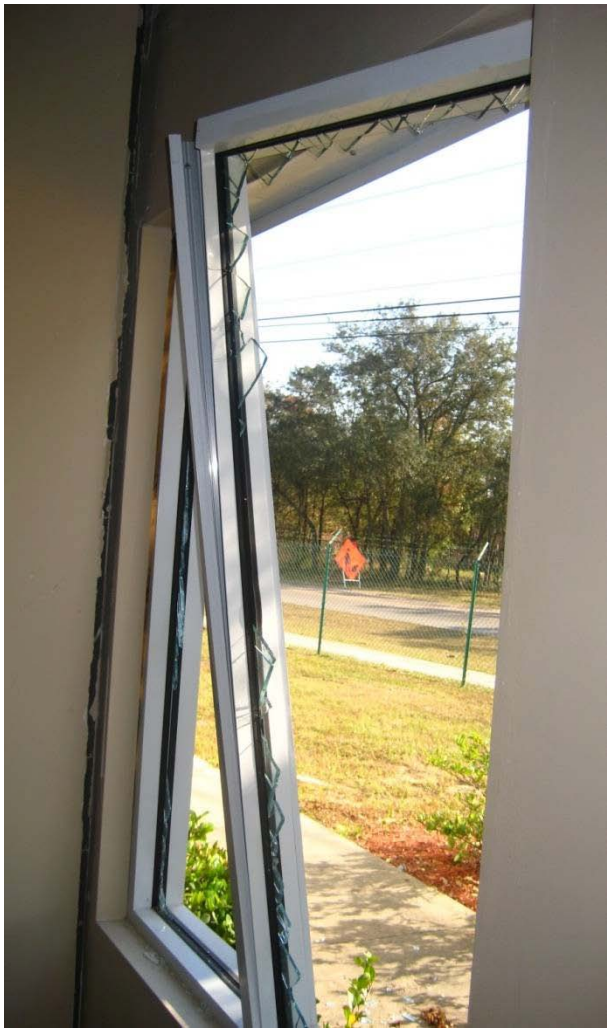
T2 Laboratories Explosion Incident
Off Site Building Damage Survey

Building 101 – K50
Hazard Level 5



Building 101 – K50
Hazard Level 5



Example Window Damage Building 501B (K75)

Building #	Property Name	Property Address
100	Stover Sales	3001 Faye Rd
101	Prezine	3041 Faye Rd
200	MastHead	3022 Haye Rd
201	PBM Construction	3000 Faye Rd
201B	PBM Construction	3000 Faye Rd
201C	PBM Construction	3000 Faye Rd
202	Refractory Repair Service	2980 Faye Rd
202B	Refractory Repair Service	2980 Faye Rd
203	Wall Street Trailers	3000-3 Faye Rd
204A	Wall Street Trailers	3000-3 Faye Rd
204B	Wall Street Trailers	3000-3 Faye Rd
300A	Tri-State Contractors	3051 Faye Rd
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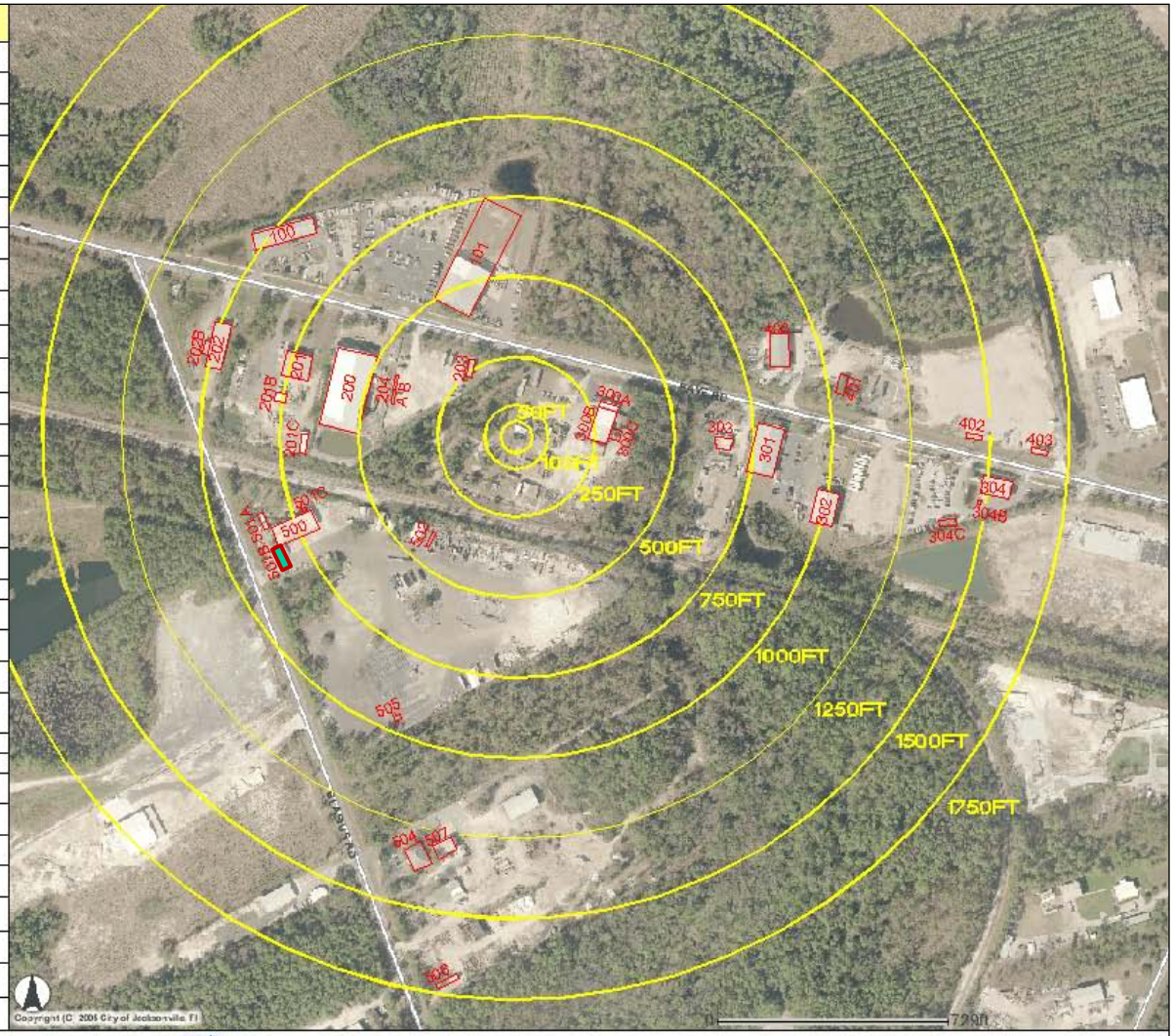
506	Petticoat Construction Company	11025 Blasius Rd
507	Petticoat Construction Company	11025 Blasius Rd



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T2 Laboratories Explosion Incident
Off Site Building Damage Survey

Building 501 – K75
Hazard Level 4

Building 501 – K75
Hazard Level 4

Shockwave Arrival

Observations

- K50
  - Two Buildings Condemned
  - High Hazard glass fragment throw
- K75
  - Repairable Damage to Pre-Engineered Buildings
  - Medium Hazard Fragment Throw

Conclusion

- Window breakage and injury were recorded at distances of K75 which is well in excess of K40 or incremental IBD.
- Potential exists to cause damage to structures and businesses as well as cause injury well outside of K40
- The T2 incident highlights the need to continue to investigate explosions and understand their consequences.