NON-THERMAL EFFECTS FROM HAZARD DIVISION 1.3 EVENTS INSIDE STRUCTURES

by

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ABSTRACT

DOD 6055.9-STD states: “Hazard Division (HD) 1.3 includes items that burn vigorously with little or no possibility of extinguishment in storage situations. Explosions normally will be confined to pressure ruptures of containers and will not produce propagating shock waves or damaging blast overpressure beyond the magazine distance specified . . . ” In some situations, however, the container may be the building in which the material is stored; thus, certain HD 1.3 events may produce enough overpressure to destroy the storage building and cause debris to be thrown about. This paper describes a series of computations made to predict the pressures that would be produced by burning HD 1.3 material under certain conditions. It will also present descriptions of testing that has been conducted showing the effects of the pressures produced by burning HD 1.3 material inside structures.

INTRODUCTION

Within Hazard Class 1 (Explosives), there are six hazard divisions. These are shown below:

TABLE 1. HAZARD DIVISIONS[1]

HAZARD DIVISION	PREDOMINANT HAZARD
1.1	Mass Explosion
1.2	Non Mass Explosion, Fragment Producing
1.3	Mass Fire, Minor Blast or Fragment
1.4	Moderate Fire, No Blast or Fragment
1.5	Explosive Substance, Very Insensitive
1.6	Explosive Article, Extremely Insensitive

The Department of Defense Explosive Safety Standard[2] states: “Hazard Division (HD) 1.3 includes items that burn vigorously with little or no possibility of extinguishment in storage situations. Explosions normally will be confined to pressure ruptures of containers and will not

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produce propagating shock waves or damaging blast overpressure beyond the magazine distance specified . . . ”

There is no argument that the predominant hazard from HD 1.3 materials is mass fire with its associated thermal flux. There is an ongoing discussion, however, about what are “minor blast or fragment” hazards. The statement from Reference (2) that “Explosions normally will be confined to pressure ruptures of containers” may be quite misleading. The container in question may be the storage structure itself. If this is the case, then “pressure rupture of containers” could lead to the destruction of the building and the production of secondary debris.

BACKGROUND

When an energetic material is burned, it is not instantaneously transformed from a solid or liquid into a gas. The burn rate varies with the ambient pressure. As the pressure increases, so may the burn rate. Such a process is called time-dependent burning. If the burning were occurring in a totally enclosed volume, the pressure would continue to increase until all of the material was consumed. At that point, the pressure would slowly begin to decrease through heat losses to the walls. The other extreme would be if the material were burned in the open. Because of the total lack of confinement, open-air burning produces no significant pressure buildup.

Real world situations will lie somewhere between these two extremes. Most structures will have some type of venting. The larger the vent area, the faster the gases that are generated can escape. If the vent area is decreased, at some point, the gases will be generated faster than they can escape. For that and smaller vent areas, the pressure will increase until all the HD 1.3 material has been consumed. Beyond that time, the pressure will decrease as the gas escapes through the vents. Because of the pressure-dependence of the burn rate, as the pressure increases so will the rate of consumption of material--causing the pressure to increase even faster. This was first examined by Sewell and Kinney in 1974[3]. The equations governing time dependent burning and the venting of the gases produced through various openings has been incorporated into various computer programs such as INBLAST[4] and BLASTX[5].

The loss of at least one ship during World War II has been attributed to the effects of burning/reacting HD 1.3 material. Ongoing analyses of the archeological records of the USS Arizona suggest that the catastrophic damage sustained by this ship during the Japanese attack on Pearl Harbor can be attributed to the burning of propellant stored within its magazines[6].

PHENOMENOLOGY

As previously discussed, time dependent burning represents competing processes–the generation and the venting of gas. Let us examine these processes more closely by computer modeling. Consider an idealized material assumed to undergo time dependent burning. The pressure dependence of the burn rate is given by the equation:

$$r = 0.00161*P^{0.741}$$

where P is pressure in psi and r is burn rate in inches/second. In this example, each grain of the material has a single perforation and has a diameter of 0.059 inches and a length of 0.394 inches.

The diameter of the perforation is 0.020 inches. The material is burning inside a chamber that has a volume of 1,000 cubic feet. The charge weight will be varied between 100 pounds and 5000 pounds and the vent area varied accordingly. The computer code BLASTX was used to perform the computations. The results are presented in Figures 1 through 4. The abscissas and ordinates of these plots are in arbitrary units. This was done because the parameters selected for the problem do not represent any real situations or propellants.

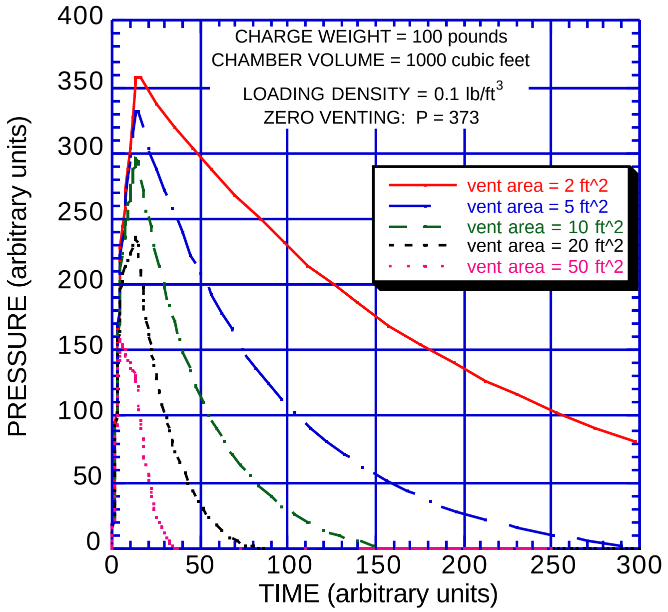

FIGURE 1. CASE 1

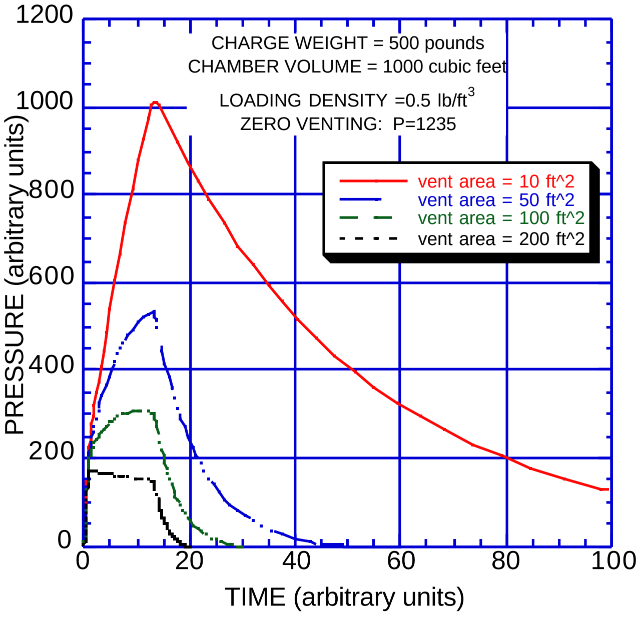

FIGURE 2. CASE 2

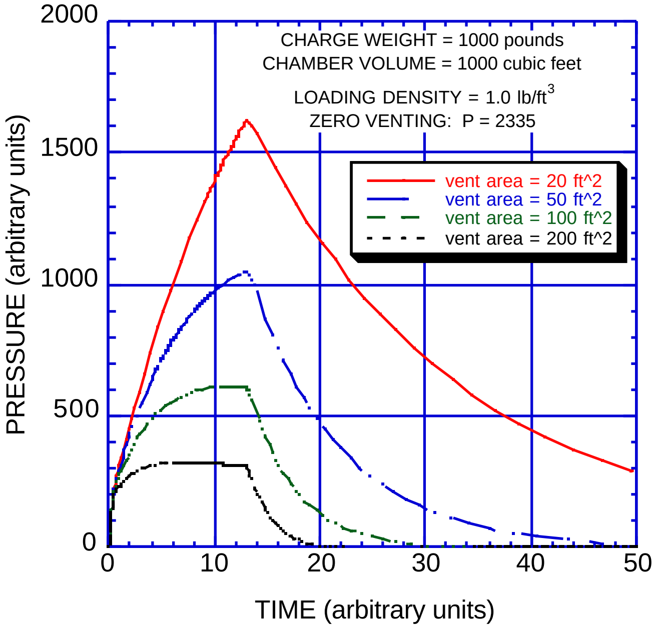

FIGURE 3. CASE 3

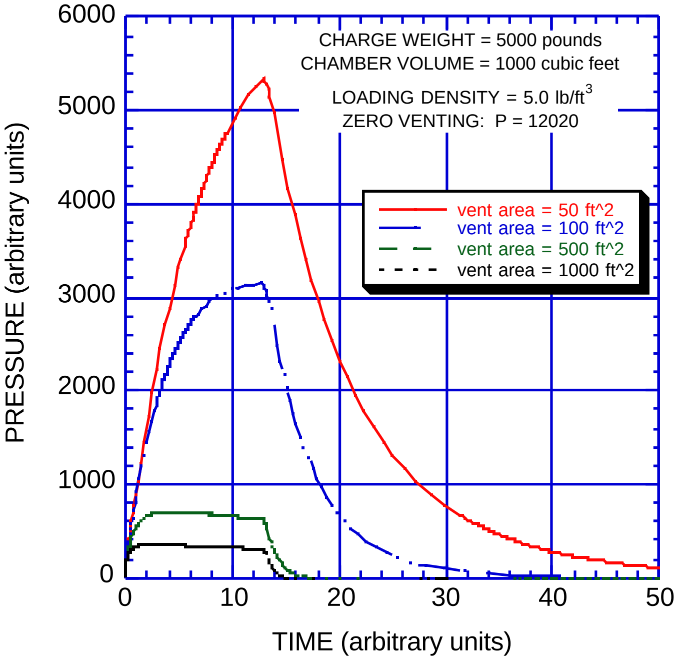

FIGURE 4. CASE 4

These four figures show what is intuitively obvious; namely, the larger the vent area, the lower the pressures that can be produced. Further, the larger the vent area, the shorter the duration of the pressurization event. These figures further show that the appropriate vent area is related to both the volume of the chamber and the weight of the energetic material involved.

If this example had represented a real-world situation, the pressures produced would probably have caused the chamber to fail catastrophically. This effort represents more than an academic exercise. Such phenomena have real world effects that must be considered. Some of these will be discussed in the subsequent sections.

REAL WORLD EVENTS

Structural Testing.[6] Since 1988, the Protection and Weapons Effects Department of the Carderock Division of the Naval Surface Warfare Center has used burning propellant to provide internal pressurization for the testing of ship structural components. When used on a properly designed fixture, propellant burns provide a static failure pressure for the structural element of interest on a single test. The structural element is subjected to increasing pressures as the propellant burn progresses and the rate of burning accelerates until the element fails or the propellant is consumed. When the structural element fails, it provides sufficient venting to stop any further pressure accumulation in the fixture, thereby dropping the burning rate and providing a maximum pressure for the event.

Under ideal conditions the fixture should be as gas tight as possible, although small leaks and premature local failures can be overcome and pressurization of the fixture continued given sufficient propellant with a high burn rate. The fixture should be sized so that failure of the structural element of interest will provide a large enough vent area to prevent further pressure buildup and quickly drop the pressure to ambient.

The methodology has some drawbacks. Because of the large amounts of heat generated, care must be exercised in both the selection of instrumentation transducers and structural materials. For example, aluminum or composite structures could lose significant strength during the time to failure-depending on the specific configuration of the test.

Structures that have been successfully tested using propellant burn pressurization include standard watertight bulkheads, the blast hardened bulkheads currently being installed on the DDG-51 Flight IIA and designed into the LPD-17, 1/4-scale models of advanced double hull concepts, improved blast resistant watertight doors, and the standard and improved connections for the fragment protection bulkheads surrounding ship magazines.

Comparisons between structures subjected to internal pressures generated by detonating high explosives to those loaded by propellant burns have shown excellent agreement between both the failure pressure and the mode of failure.

Figure 5 shows one of the test fixtures. It has nominal dimensions of 9’ x 8’ x 12.75’ and a volume of 918 ft^3. When approximately 300 pounds of propellant were burned in this fixture (loading density of 0.33 lbs/ft3), catastrophic failure occurred. This is shown in Figure 6.

Air Force Air National Guard Facility. An analysis was recently completed for an Air National Guard facility that could store up to several thousand pounds of HD 1.3 pyrotechnic material. One of the purposes of the study was to determine the loading produced by the burning of various amounts of the HD 1.3 material. These loadings were then used to determine if the structure could survive the event; i. e., whether or not failure of the walls would occur.

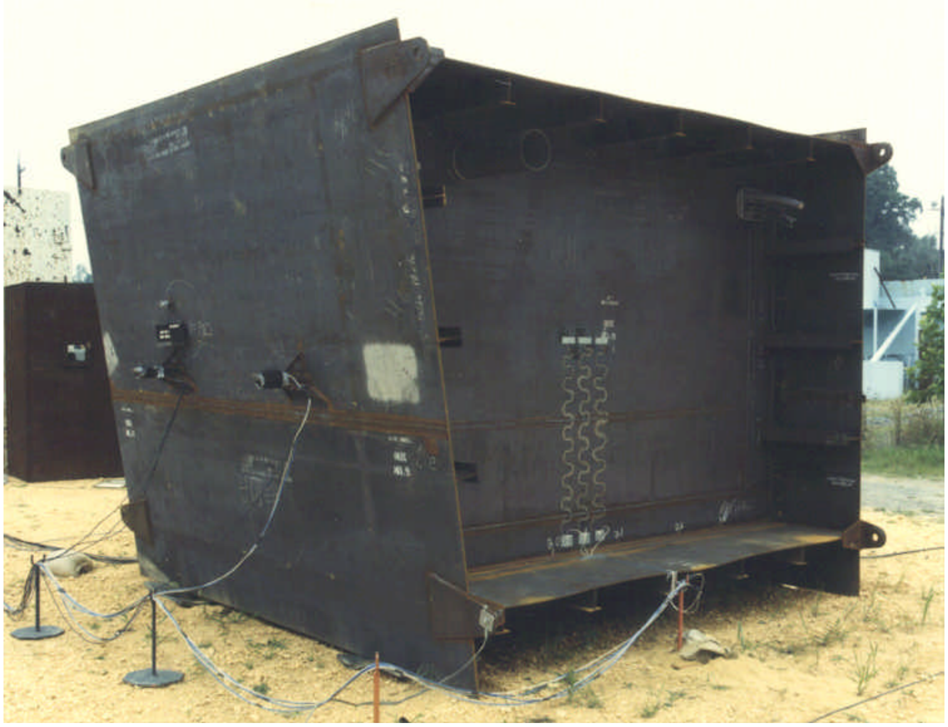

FIGURE 5. REDUCED VOLUME COMPARTMENT TEST--PRE-TEST

FIGURE 6. REDUCED VOLUME COMPARTMENT TEST--POST-TEST

Figure 7 below shows the layout of the structure analyzed for this problem. The primary features of this structure include: (1) two bays separated by a CMU (concrete masonry unit) wall, (2) outside walls of each bay constructed of 12-inch reinforced concrete, (3) doors at each end of each bay, (4) each bay divided into cubicles and a passageway by 6-inch reinforced concrete stub walls (partial width wall), and (5) heavy duty built up roof. For computational purposes, the structure is symmetrical and only one side has to be analyzed.

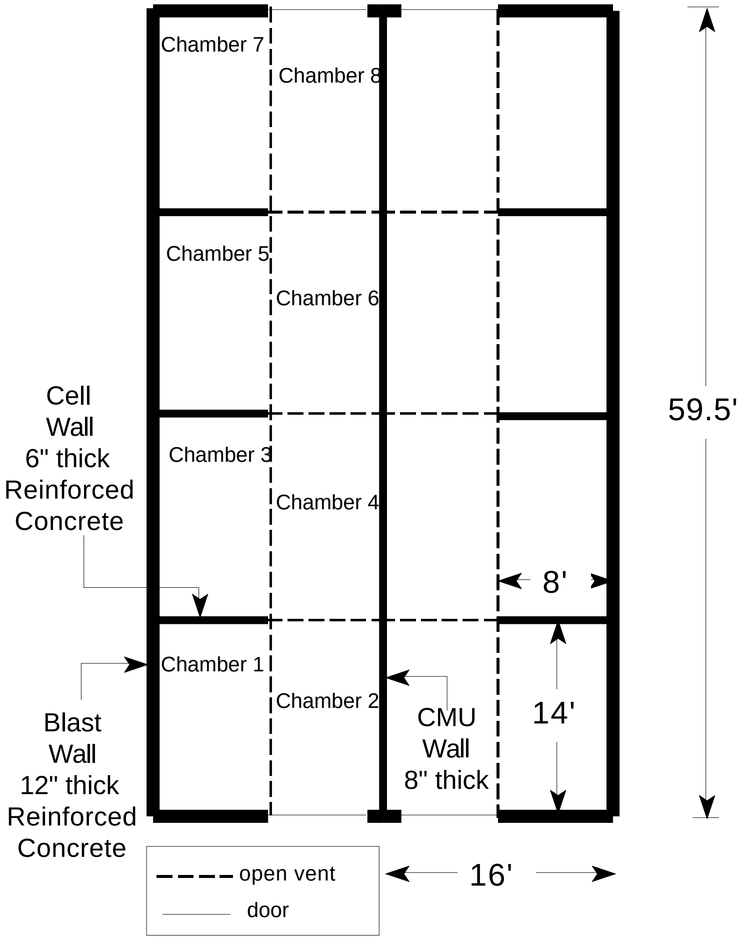

FIGURE 7. AIR NATIONAL GUARD STRUCTURE

Table 2 provides the structural details used in the computations. This information includes dimensions and volumes of the chambers and a description of the various vent areas assumed. The roof is hardened and the outside walls of each bay extend through the roof of the structure.

The HD 1.3 material most likely to be stored in these facilities are flares or other pyrotechnic devices. Each of these devices can contain as much as two pounds of pyrotechnic material--usually a magnesium-Teflon composition. Neither BLASTX nor INBLAST is currently equipped to handle the chemistry associated with burning Teflon; i.e., the codes cannot directly handle reactions involving halogen compounds. To compensate for this deficiency, a hybrid substitute was used. The material was assumed to have the chemistry of M1 propellant but with a magnesium-Teflon burn rate. This combination produces large amounts of gas very quickly. M1 propellant chemistry

TABLE 2. AIR NATIONAL GUARD STRUCTURE INFORMATION

CHAMBER NUMBER	DIMENSIONS (ft)	VOLUME (ft^3)	VENT NUMBER	CHAMBERS CONNECTED	VENT AREA (ft^2)	OPENING CRITERION	DESCRIPTION
1	16 x 8 x 10.25	1152	1	1--2	144	open	passageway
2	16 x 8 x 10.25	1152	2	3--4	144	open	passageway
3	16 x 8 x 10.25	1152	3	5--6	144	open	passageway
4	16 x 8 x 10.25	1152	4	7--8	144	open	passageway
5	16 x 8 x 10.25	1152	5	2--4	96	open	passageway
6	16 x 8 x 10.25	1152	6	4--6	96	open	passageway
7	16 x 8 x 10.25	1152	7	6--8	96	open	passageway
8	16 x 8 x 10.25	1152	8	2--outside	59	p=0.1 psi	door failure
			9	8--outside	59	p=0.1 psi	door failure
			10	1--outside	50	p=10 psi	localized roof failure
			11	2--outside	50	p=10 psi	localized roof failure
			12	3--outside	50	p=10 psi	localized roof failure
			13	4--outside	50	p=10 psi	localized roof failure
			14	5--outside	50	p=10 psi	localized roof failure
			15	6--outside	50	p=10 psi	localized roof failure
			16	7--outside	50	p=10 psi	localized roof failure
			17	8--outside	50	p=10 psi	localized roof failure

is already built into both computer codes. The following burn rate for magnesium-Teflon compounds, taken from Reference 7, was used in these calculations:

$$r = 1.436*P^{0.22}$$

where r is in inches/second and P is in psi. Calculations were performed for several scenarios: (1) 1250 pounds burning in Chamber 1, (2) 2500 pounds burning in Chamber 1, (3) 312.5 pounds burning in Chamber 3, (4) 625 pounds burning in Chamber 3 and (5) 1250 pounds burning in Chamber 3. Based on symmetry, the results obtained for Chamber 1 also apply to Chamber 7 and the Chamber 3 results will apply to Chamber 5.

Figures 8 and 9 show typical results obtained for the burning of 1250 pounds in Chamber 3. Table 3 presents a summary of all of the results obtained. Examining Table 3, it appears that when equal weight events are considered (1250 pounds in each chamber) events in Chamber 3 produce higher pressures than those in Chamber 1. This is because this chamber is farther from the doors--reducing the venting through these spaces.

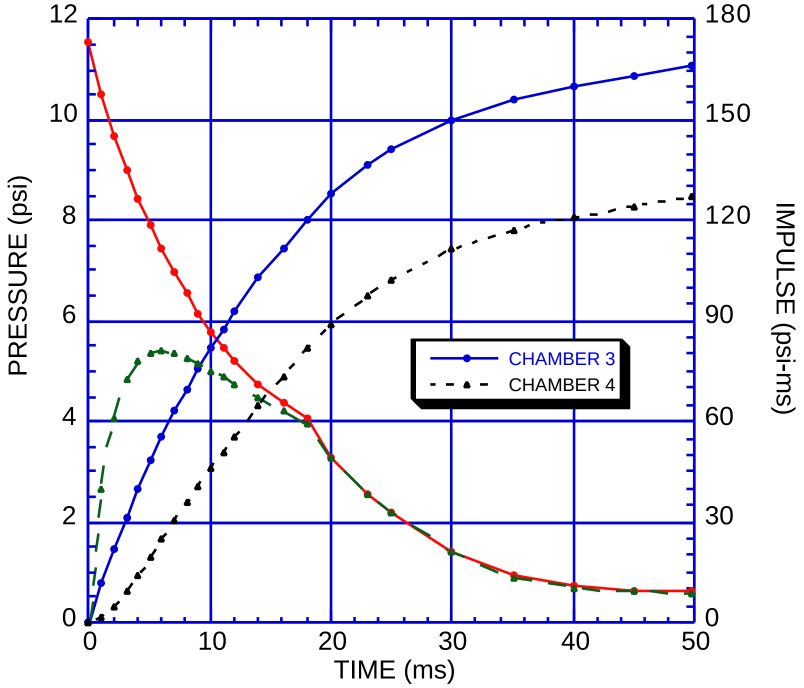

FIGURE 8. 1250-POUND BURN IN CHAMBER 3

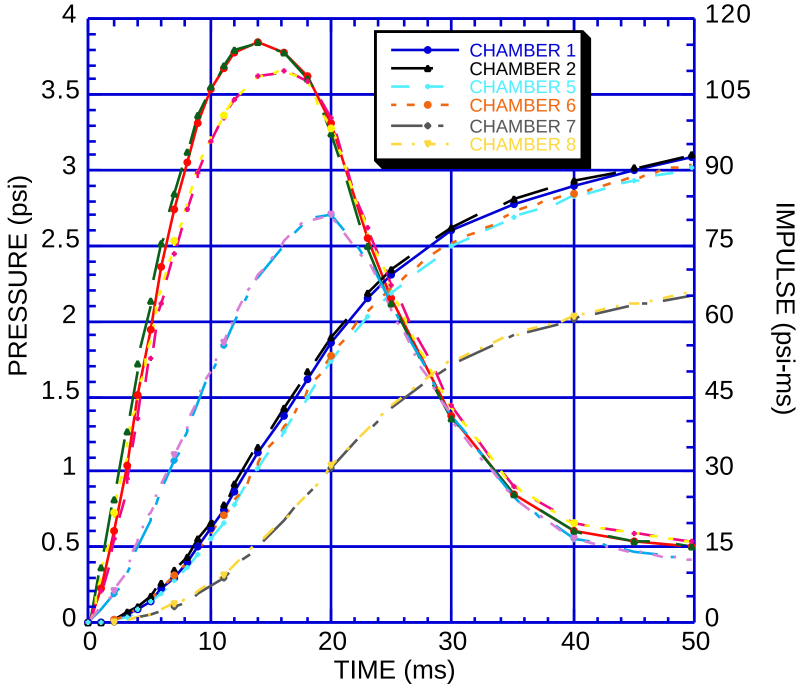

FIGURE 9. 1250-POUND BURN IN CHAMBER 3

TABLE 3. MAXIMUM PRESSURE IN EACH CHAMBER

CHAMBER NUMBER	WEIGHT BURNED/LOCATION				
	1250 POUNDS CHAMBER 1	2500 POUNDS CHAMBER 1	312.5 POUNDS CHAMBER 3	625 POUNDS CHAMBER 3	1250 POUNDS CHAMBER 3
1	11.52	22.21	1.38	3.58	3.85
2	6.17	12.31	1.38	3.58	3.85
3	3.77	6.61	2.93	5.84	11.54
4	3.77	6.62	1.71	4.12	5.40
5	2.57	3.79	1.46	3.71	3.66
6	2.57	3.79	1.46	3.71	3.66
7	1.82	2.48	1.11	2.95	2.71
8	1.82	2.48	1.11	2.96	2.71

NOTE: all pressures are in psi

The pressure-time and impulse-time profiles generated were used as the loading functions for the walls of the structure. A structural analysis performed by the Naval Facilities Engineering Services Center suggested that the 12-inch reinforced concrete walls could withstand the effects of burns of over 500-pounds. The 6-inch reinforced concrete walls could withstand the burns of about 300 pounds. These results, however, are very dependent upon the construction of the walls and how they are fixed along the edges. Because of this, it is difficult to generalize the consequences. However, a conservative estimate is that if more than 300-pounds of material were burned, the walls would probably fail from overpressure.

French Captieux Trials.[8] During the period 1990-1991, the French conducted a series of trials in 1/3-scale models of earth-covered magazines. Four tests were conducted. Each used approximately 2500 kilograms of gun propellant. The volume and design of each structure varied slightly. However, the nominal volume was about 25 m^3. This gave a nominal loading density for the trials of 100 kg/m^3 (6.25 lb/ft^3). The gun propellant was a single based material with a grain containing seven perforations. The following is a summary of the results obtained on these four tests:

Shot 1: Large plume formed out the front of the igloo. The rear of the structure lifted off the ground and then opened up, allowing a second plume to form out the rear.

Shot 2: Structure remained intact but lifted off the ground.

Shot 3: Approximately 2-3 seconds into the burn, explosion of igloo occurred. No overpressure recorded on any external pressure transducer.

Shot 4: Approximately 1 second after ignition, igloo explodes. Pieces of structure thrown over 25 meters.

Figures 10 through 12 show before and after photographs of Shot 4 of the Captieux trials.

FIGURE 10. SHOT 4 (CAPTIEUX TRIALS)--BEFORE EVENT

FIGURE 11. SHOT 4 (CAPTIEUX TRIALS)--POST EVENT

FIGURE 12. SHOT 4 (CAPTIEUX TRIALS)--POST EVENT 2

DISCUSSION

As has just been shown somewhat anecdotally, the effects of burning HD 1.3 material inside a closed structure can range from benign to catastrophic. If adequate venting is not provided, the pressure can build up at such a rapid rate that it can overwhelm the structure. This explains why it is safest to store HD 1.3 materials in structures that provide large amounts of venting. In above-ground structures, this venting is provided through frangible walls and/or roofs. When HD 1.3 materials are stored in hardened structures or any other structure that provides structural confinement, extra care should be taken to provide adequate venting. The amount of venting required varies with the volume of the storage chamber, the weight of the material being stored, and its burn rate.

These phenomena are not adequately addressed in the current versions of the explosive safety standards--either from the standpoint of safe separation distance or asset protection. Future revisions to the safety standards should begin to address this issue.

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