Realistic Assessment of Hazard Division 1.3 Events

Authors:

Maurice "Chip" Muser IV, MSc; Nammo Raufoss AS; Raufoss, Norway

Hans Øiom, Senior Engineer; Norwegian Defense Material Agency/Ammunition Safety; Raufoss, Norway

Keywords:

Hazard Division 1.3, Quantity distance, Heat flux, Explosive site plan, Energetic materials

Abstract:

Risk assessment of accidental explosive events based upon the quantity and hazard division (HD) of the energetic material involved in the event is the default method for addressing explosives safety risks. Different HDs undergo different types of reactions and therefore should be evaluated using different methods.

Calculating quantity distances (QD) between potential explosion sites and exposed sites using cube root scaling based upon the total mass of explosives is conducted to develop QD tables. While this approach is effective for relatively large HD 1.1 events due to the detonation characteristics of such materials, the total mass of HD 1.3 materials do not correlate well to the primary hazard for HD 1.3: heat flux resulting from mass fire. Energy density of a substance has a significant impact upon the heat flux from a given event as does the distance from the event and exposure time.

Safety distances based on engineering analysis for individual scenarios may result in a more realistic risk assessment than relying upon QD tables alone.

Introduction:

Current methodology for calculating safe separation distance from incidents involving HD 1.3 energetic materials rely primarily on Quantity Distance (QD) criteria using cube root, exponential or logarithmic functions depending upon national regulations and the quantity of the energetic material in question. However, while weight based QD criteria may be adequate for determining risks involving HD 1.1 materials undergoing detonation reactions which consume nearly all of the energetic material involved in an event simultaneously to produce a blast wave which creates an overpressure condition and fragmentation; the primary hazard from HD 1.3 materials is mass fire and the ensuing high levels of heat flux. Tests have shown that the entire mass of HD 1.3 materials are not always consumed in accidents or tests since such events progress more slowly dependent upon the type of HD 1.3 materials (propellant powders, composite rocket motors, etc.), packaging or the casing in which the materials are contained. The energy content of HD 1.3 materials varies widely and both NATO AASTP-1 and the United Nations International Ammunition Technical Guideline 01.50 provide a further division into HD 1.3.1 and HD 1.3.2 based upon the material's potential for mass or moderate fire, projection of firebrands, fragments and intense radiant heat.

Second and third-degree burns to personnel resulting from fire and the resultant high levels of high heat flux are the primary hazard to personnel from HD 1.3 events. Secondary fragmentation can be a hazard if inadequate venting of the room/building containing HD 1.3 materials results in "choked flow". Earlier work by the Department of the Defense Explosives Safety Board (DDESB) and the Naval Air Warfare Center Weapons Division served as the inspiration for our short investigation into this subject and both highlighted the shortcomings of the current weight-based approach for siting HD 1.3 materials. Two papers written in 2010 and 2013 identified that a purely weight-based approach to HD 1.3 material siting does not account for factors such as:

- Initiation energy
- Reaction rate
- Article in which the HD 1.3 material is embedded
- Energy density of the substance
- Critical diameter or total mass of the substance
- Confinement of buildings or technical equipment due to inadequate venting area (choked flow)
- Cause of fatalities

This paper will briefly look at some methods used by several European nations and the United States to calculate QDs for HD 1.3 materials. A review of these methods illustrates the range of values resulting from different equations currently in use. After the disparities in weight-based QD calculations are discussed; a short review of one accident and two tests involving HD 1.3 materials are used to highlight the variations among results from different calculation methods versus real world observations. Finally, a practical example of a production facility working with HD 1.3 materials at Nammo Raufoss AS in Norway is used to demonstrate how engineering analysis might be used to determine safe separation distances to more realistically reflect the hazards in such a when compared to relying solely upon QD based calculations.

Complex problems require comprehensive engineering analysis to determine the hazards to personnel in a given operation and considering the factors above allow us to make improved decisions regarding risks associated with HD 1.3 materials. Safe separation distance in a particular direction may increase beyond the current QD based distances due to venting and orientation of products within a given room/building that may better represent the hazard from fireballs or flame jets resulting from HD 1.3 events. At the same time, safe separation distance may be reduced to near zero in other directions when the intensity and duration of an event is determined relative to building construction that offers shielding to personnel. Overall, the footprint of facilities manufacturing, handling and storing HD 1.3 materials could be reduced with thorough analysis.

Discussion:

Examination of NATO and US QD tables for HD 1.3 materials

Quantity Distance for HD 1.3.1 according to Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives, AASTP-1 is given by k-factor 6.4 with cube root scaling as shown in the following equation:

$D=6.4*Q^{1/3}$ where: D=distance, K=6.4, and Q=Net explosive quantity, with a minimum distance of 60m

NATO STANAG 4440 provides the basis for the equation found in AASTP-1, which is to produce 4 cal/cm^2 (radiated energy based on 10,000 kg at K-factor 6.4)

The United States (US) Department of Defense (DOD) Contractor's Safety Manual for Ammunition and Explosives Safety, 4145.26-M offers another set of equations for HD 1.3 QD based upon a range of net explosive weights for quantity distance (NEWQD). Note that the US manual does not subdivide HD 1.3 materials into HD 1.3.1 and HD 1.3.2.:

NEWQD < 453.6 kg, dIBD, PTRD = 22.9
453.6 kg < NEWQD < 43,544.6 kg

$dIBD, PTRD = exp[1.4715 + 0.2429*(ln(NEWQD)) + 0.00384*(ln(NEWQD))^2]$ ***[EQN C9.T13-4]***
with a minimum distance of 22.9 m
43,544.6 kg < NEWQD < 453,590 kg

$dIBD,PTRD = exp[5.5938 - 0.5344*(ln(NEWQD)) + 0.04046*(ln(NEWQD))^2]$ ***[EQN C9.T13-5]***
NEWQD > 453,590 kg
$dIBD, PTRD = 3.17*NEWQD^{1/3}$ ***[EQN C9.T13-6]***

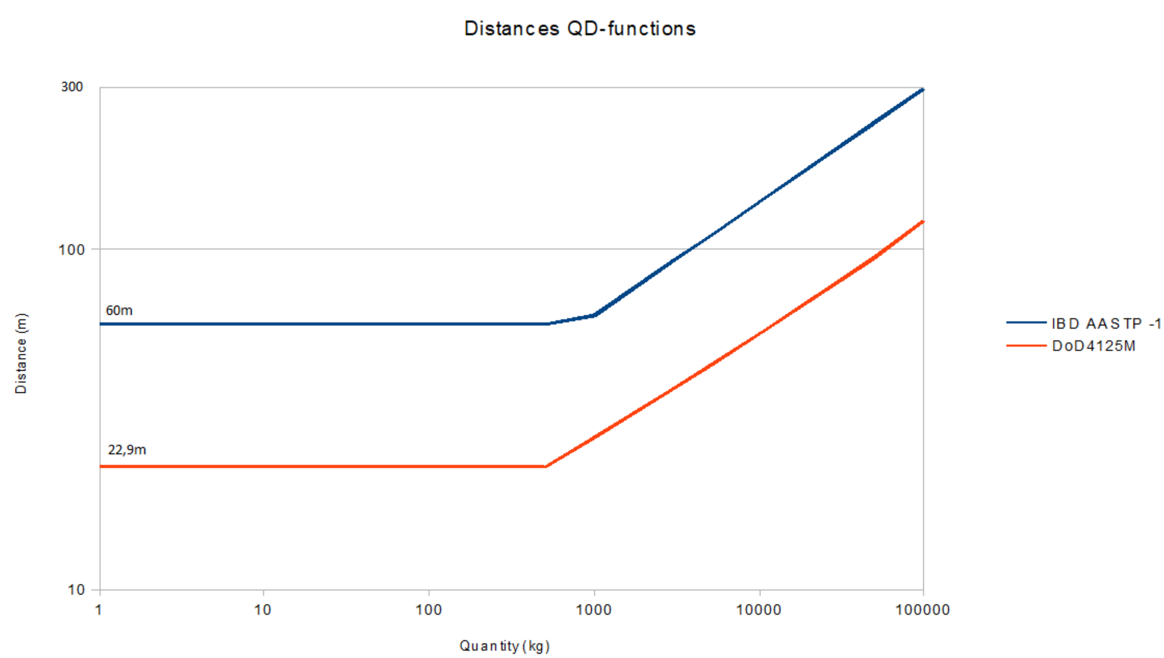


Figure 1. QD functions for HD 1.3 from DOD 4145.26-M vs. QD functions for HD 1.3.1 from AASTP-1, logarithmic scale

Examining ***Figure 1*** shows that AASTP-1 provides a more conservative estimate of QD for HD 1.3.1 materials when compared to QD calculations utilized in DOD 4145.26-M for HD 1.3. The QD values utilized by DOD 4145.26-M are approximately 41% shorter than those required by AASTP-1 are. Both of these calculations are based upon the NEWQD and not upon the primary effect of HD 1.3 materials: mass fire. Other models attempting a more physical approach have been developed to model the hazards associated with HD 1.3 material based upon heat flux and lethality from burn injuries.

In order to compare models based on calculations of radiation and lethality with values from the QD tables, we must determine a likelihood for lethality provided by the distances in the QD tables. It appears to be accepted that the QDs in AASTP-1 provide a safety distance that will result in lethality of less than one percent (*Note: assigning a lethality value to QD tables is complicated and it has been found that risk built into tables in AASTP-1 varies with at least three orders of magnitude*). Fragment criteria of one fragment per $56m^2$ with an impact energy of 79 Joules (J) is utilized in determining acceptance criteria for QD. In reality, this is an average lethality less than 1%, for the assumed area of a human body of 0.56 m^2. The fragment could strike anywhere on the body such as an arm or leg and 79J is not lethal for a random hit in the torso. On the other hand, the lethality curves are quite steep, so it takes a relatively short distance for the lethality to rise considerably.

NATO AASTP-4 Part II contains models for comparison provided by several nations. We have chosen to focus on three of the methods offered by Norway/Sweden (NO/SW-1%), Switzerland (CHE-1%), and the Netherlands (NL-1%). Performing such comparisons is not a simple task and the three models were chosen with a set of assumptions. Assumptions include the chosen 1% lethality criteria, model validity from 1 to 100,000kg, light clothing for exposed personnel, energy content of propellant equal to 6000J/kg.

The model listed as the Norwegian/Swedish model is based on a SNPE/TNO paper from the 1990s. In 2008, the model provided by Netherlands/TNO was updated to replace an earlier version while the Swiss model was last updated in 2002.

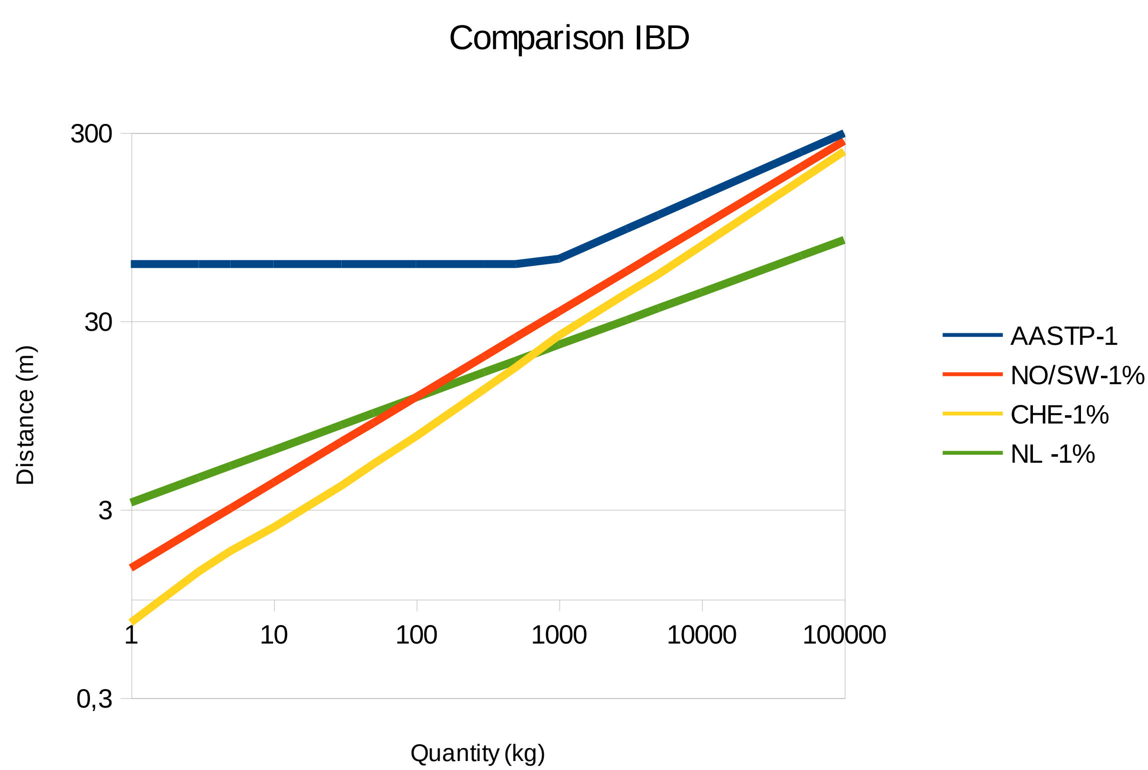


Figure 2. Inhabited Building Distance comparisons, logarithmic scale

Comparing models show different rise coefficients in a log/log plot. AASTP-1 distance is obviously increasing with the cube root after the minimum distance ceases to apply at 1000kg. In addition, the TNO model from the Netherlands is not far from cube root scaling. Distance rises a bit more steeply than the cube root scaling in the other models. It is not obvious that cube root scaling offers the optimum relationship. Vulnerability to heat, intuitively for most people, has an intensity factor as well as a duration factor. It is doubtful if this effect proved scalable based on a cube root exponential function.

The minimum distance of 60m is based upon fragmentation from the items and packaging. If the HD 1.3 material is in a structure with a frangible wall and packaging that does not contribute to the fragmentation hazard, this distance could be reduced to the critical lethality distance for heat flux.

Examples from one accident and two tests:

Accidental ignition with small quantity of black powder

About ten years ago, two Norwegian EOD officers had an accident while burning propellant. Approximately 0.5kg of black powder was discovered during a housing renovation project and was subsequently sent for destruction. The officers brought the bag of propellant to a nearby field in order to burn it. They rigged the bag at ground level with a 0.5m fuse. However, the operators failed to secure the fuse, which curled up upon ignition and ignited the powder while one of the officers was about 0.7m away from the charge; approximately arms-length.

Luckily, the incident occurred during wintertime and snow was immediately applied to cool the exposed skin that was burned as result of the inadvertent ignition. In addition, the affected officer was wearing glasses; therefore, his eyes were shielded from burning particles. His face was kept moist and cooled for half an hour on the way to the hospital. Following a medical check, he was dismissed and advised to avoid exposure to bright light for several days. A thin layer of skin peeled off from his face similar to a mild sunburn, but without pain or discomfort. From a personnel injury perspective, this injury is roughly equivalent to an abbreviated injury scale (AIS) severity code of 2-3.

Black powder has a high burning rate, low ignition energy and relatively low energy density (3MJ/kg). Unlike smokeless powder, all of the material is usually consumed in the fire. The fireball diameter, calculated to be 1.9m using a formulae valid for small quantities ($2.7*Q^{0.5}$), does not take into account the relatively low energy density of black powder.

According to the Norwegian/Swedish calculation method of heat-flux from AASTP-4 and lethality from heat-flux, the probability of lethality at 0.6m should be about 4%. The operator was probably moving backwards when the powder ignited. One meter separation distance from the event yields a probability for event lethality of 1×10^{-5}. With the uncertainties and approximations in this event, the Norwegian/Swedish model agrees reasonably well with the observed effects to the injured officer.

Propellant tests in Lapland-Finland

In the NATO AC/326 SG C meeting in Rome-September 2017, Finland presented findings from a test in which propellant was ignited within a container to observe the effects on the primary container and a neighboring container that also contained HD 1.3 propellant. The intention of the test was to look at the response of ISO-containers loaded with propellant. Two standard 40-foot ISO-containers were placed on the ground as commonly found in staging areas with a separation distance of 1.5m.

Figure 3. Finnish test container with fiber drums containing HD 1.3 propellant

Large and medium caliber propellant packaged in cardboard drums was used to load the container. The first container had a load of 16 tons of propellant while the other was loaded with 12 tons. In the first container, two drums of propellant were ignited; one located just inside the door and the other at the rear of the container.

Figure 4. Finnish test container approximately 1-2 seconds after propellant ignition

After the fire had burned for two seconds, the doors burst open and a directional flame jet erupted from the end of the container. Estimated flame jet length was approximately 100m seven seconds after ignition. Following the initial flame jet, a fireball with an estimated diameter of 30-35m was produced and reached maximum intensity approximately 10 seconds after ignition.

Figure 5. Finnish test container approximately 10 seconds after propellant ignition

Combustion gases rapidly filled the container and once pressure attained a high enough value, the front doors opened to provide a vent path resulting in the flame jet that was observed. After the first ten seconds, the fireball abated and the fire continued with diminishing intensity as the remaining propellant and packaging material burned. During the test, the wind was blowing towards the doors of the containers and as result, the fire was pushed towards the doors and between the containers. Contents of the second container began to burn after approximately one minute and 40 seconds. Pulsing directional fires burned for two and half minutes.

Figure 6. Finnish test containers after ignition of second container

Residue from packaging was found along the path of the flame, but not more than 100m from the container doors.

Most QD based risk analyses would have considered the two containers as one quantity. However, during this test the second container did not ignite instantly, but rather took over a minute and a half to ignite. Considering a similar scenario in a production building with two similar quantities of HD 1.3 materials to the test just discussed we can see that siting the two rooms, as a single quantity may not be assumption that provides the most realistic assessment of the hazard.

Two rooms separated by concrete walls on three sides with frangible walls sized to provide adequate venting to prevent choked flow and equipped with a sprinkler system would help mitigate the risk to operating personnel. During this test, no sprinklers were installed to observe their potential effect on the spreading of the fire and the walls of a metal container are a much weaker barrier than reinforced concrete.

Norway/Sweden	Switzerland-fast	Switzerland -slow	Netherlands	United Kingdom	United States
88m	101	25	32	23	48
$3,8Q^{0,325}$	$4Q^{(1/3)}$	$Q^{(1/3)}$	$0,45Q^{0,44}$	$1,7Q^{0,268}$	$1,5Q^{0,36}$

Figure 7. Fireball diameter prediction model calculations for 16 tons of propellant according to AASTP-4 Part II

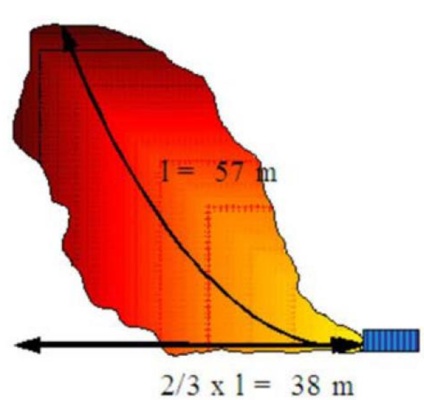
The fireball equations in the Netherlands and the US chapters appear to offer the closest estimates to the actual fireball observed during the 16-ton event test conducted in Finland. From the 12-ton event more of a jet was formed, but it seems the less conservative predictions in the UK chapter and slow events as stated in the Swiss chapter are most representative.

Norway/Sweden 1% lethality	Switzerland 1% lethality	Netherlands 1% lethality	US DOD 4145.26-M	NATO AASTP-1
117m	94m	49m	66m	161m

Figure 8. IBD for 16 tons of propellant from several standards

Clearly shown in ***Figure*** 8, the differences for calculated IBDs for 16 tons of HD 1.3 propellant are considerable. Both the Norwegian/Swedish and the NATO AASTP-1 distances are extremely conservative compared to what was observed during the Finnish test, while the prescribed QD from the Netherlands appears to provide a much less conservative distance. However, the model may not valid for this kind of event.

According the Netherlands thermal chapter in AASTP-4 Part II, the flame jet length can be calculated by the following equation: *Flame jet length = 5.49*NEQ*$^{0.28}$



The jet flame length and its projection at ground level

Figure 9. Flame jet calculation figure from AASTP-4

Employing the equation shown above for the 16 tons of propellant in the Finnish test, we obtain a calculated flame jet length of 83m, which corresponds well with observations during the test. As the illustration in ***Figure 9*** from AASTP-4 shows, the effective projection of the flame jet along the ground would be equal to two-thirds of the calculated distance of 83m (56m).

US DOD 6055.09-STD paragraph C2.4.3 provides a method to calculate the diameter of a fireball resulting from an event involving HD 1.3 materials.

> *DFIRE = 10 x WEFF$^{1/3}$; where "DFIRE" is the diameter of the fireball (ft) and "WEFF" is the quantity of HD 1.3 involved (lb), multiplied by a 20 percent safety factor (e.g., "W" of 100 pounds = "WEFF"of 120 pounds)*
> *[DFIRE (meters) = 3.97 x WEFF$^{1/3}$ (kilograms)*

Using the equation above, the estimated diameter of the fireball from 16 tons of propellant would be approximately 100m, which is quite a conservative estimate of the fireball diameter due to the 20% safety factor applied to the NEQ to derive an effective weight. However, none of the QD tables for HD 1.3 materials makes mention of the fireball diameter calculations and how they can be applied to a reduction or increase in QD. Additionally, the calculations are both based upon weight and not upon the effects of the fireball, radiated heat and the resultant burn injuries to personnel. Depending upon the exposure time of personnel to the fireball and the heat flux generated, varying degrees of injury may result.

Calculation of heat flux from burning HD 1.3 materials over time could provide a better method to evaluate the real hazard to personnel. Heat flux is briefly discussed in US DOD Manual 4145.26-M paragraph 5.7.1.3 where the manual states that personnel conducting operations remotely should be protected to ensure that heat flux does not exceed 0.3 calories/cm^2-sec (12.56 kw/m^2). The time component of exposure to heat flux is important and according to research conducted by Ezekoye and Diller (2006), second-degree burns will occur after approximately eight seconds of continuous exposure to a heat flux of 12.5 kw/m^2.

Determining the heat flux from a given amount quantity of HD 1.3 materials could allow us to identify a safe separation distance that adequately accounts for the primary hazard to personnel rather than making overly simplistic assumptions based purely on the quantity of energetics involved in a potential incident. Further research into the effects of thermal flux upon personnel with various types of barriers and types of protective clothing would help better define the risks.

Test 2011 -2013 by DDESB, Propellants in concrete cubicles

Following a thorough analysis of accidents, the DDESB set up a series of tests to collect results on HD 1.3 materials in structures. Four test setups were chosen for concrete cubicles with varying loading density and venting areas. As stated in the introduction, confinement influences the reaction rate and HD 1.3 materials tend to have rapidly increasing reaction rates if venting is inadequate. Two of the tests were designed to build up pressure in the structure to simulate choked flow scenarios. The other two tests simulated unchoked flow conditions. M1 large caliber gun propellant packaged in cardboard drums was utilized for the tests. Details of the test can be found in reports and briefings by DDESB.

Test 1-Unchoked flow	Test 2-Unchoked flow	Test 3-Choked flow	Test 4-Choked flow
130kg propellant	533kg propellant	120kg propellant	503kg propellant
Predicted flame jet 21.5m	Predicted flame jet 32.2m	Predicted flame jet 21m	Predicted flame jet 31.5m
Predicted fireball* 3.8-20m	Predicted fireball* 7.1-33m	Predicted fireball* 3.7-20m	Predicted fireball* 7.0-32m

Figure 10. Predicted fireball and flame jet from DDESB tests (* the range of predicted fireball represent different models given in AASTP-4 part II for different reaction rates)

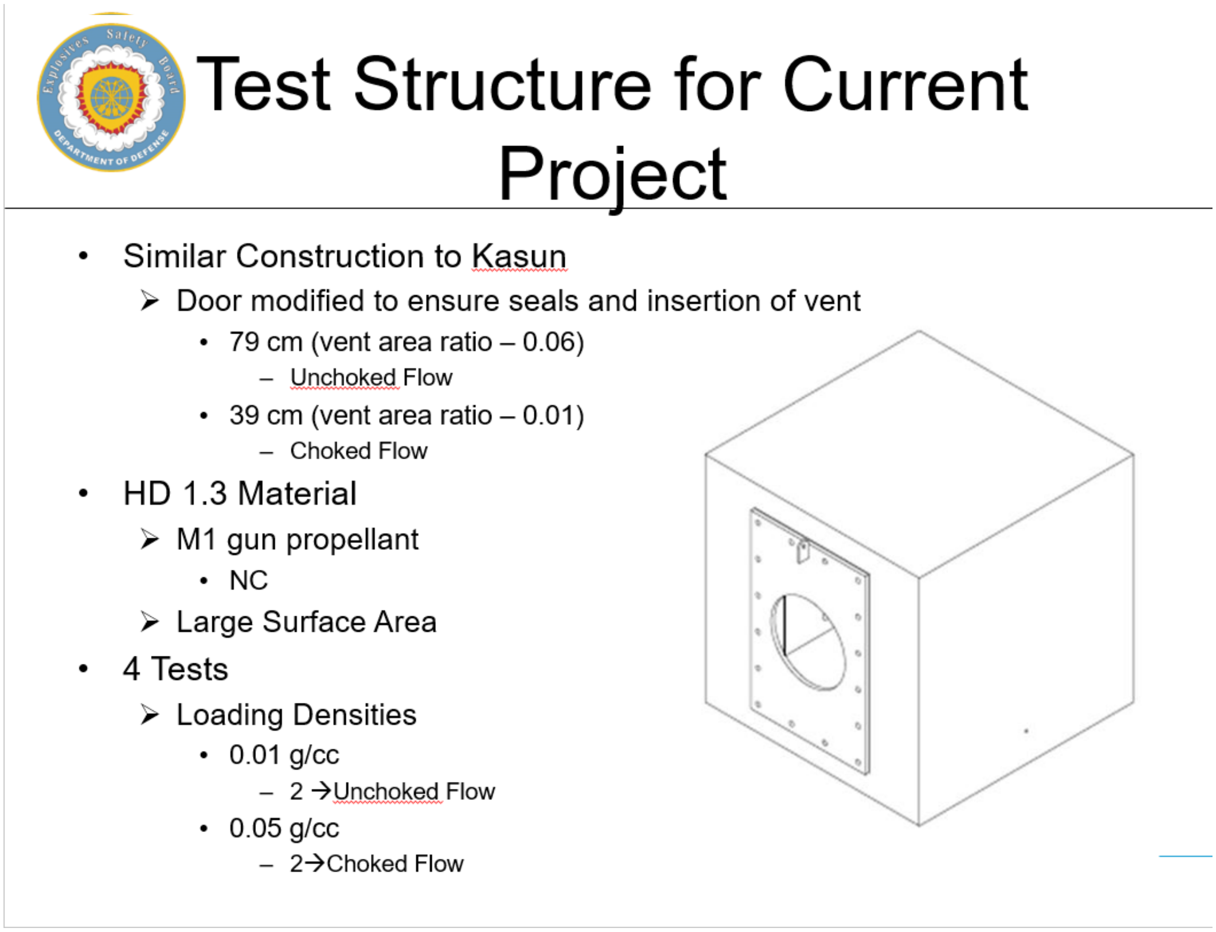


Figure 11. DDESB Test structure description

Figure 12. Image from DDESB test 1 with 130kg of propellant

In ***Figure 12***, a flame jet approximately 2m wide and 12m long can be seen erupting from the opening on the back of the structure. The volume of this burning plume is equivalent to a fireball diameter of 5 m. This is in the region of the predicted for the models from the Netherlands and Switzerland in AASTP-4 Part II.

From the available videos of test 4 and presentation, an estimated 30m flame jet formed before the choked flow event ruptured the test structure. The flame appeared 2.5 seconds after ignition and increased in intensity and length until the structure ruptured.

Figure 13. Image from DDESB test 4 with 503kg of propellant simulating choked flow

Figure 14. Image from DDESB test 4 with 503kg of propellant after rupture of structure

When the structure ruptured due to overpressure, the flame jet transitioned to form a fireball. The fireball lasted about 20 seconds before dropping in intensity; from the limited view, the fireball appeared to have a diameter of 12m.

This event fits well with the prediction of the fireball according to the US model and seems to fall between a fast and slow event according to the Swiss model. The 1% lethality was predicted as close as 17m for the Swiss model, 19m for the Netherlands model and 19.5m for the Norwegian/Swedish model. Apart from the eccentric effect of the fireball (influenced by wind and the breakup), the model predictions appear to be accurate.

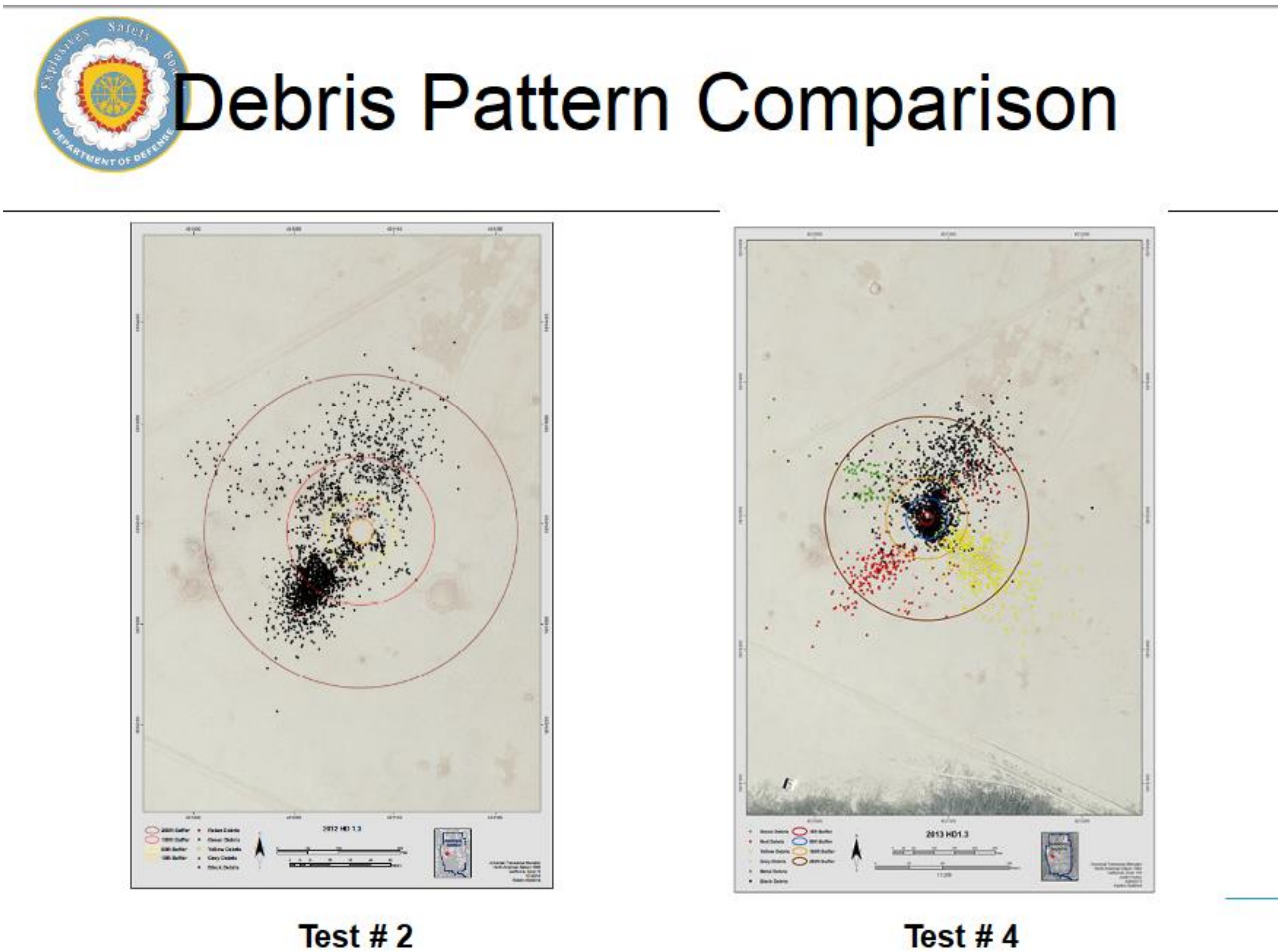


Figure 15. Image from DDESB tests showing debris fields

Debris from the structure in the choked flow condition shown in Test #4 from ***Figure 15*** was largely found close to the middle ring denoting the NATO IBD criteria for HD 1.3.1 materials. The outer circles mark the one fragment per $56m^2$ criteria while the inner circle denote heat flux criteria. This was done to demonstrate that for a choked flow condition, the effect of structural debris must be accounted for.

Example scenario from rocket motor production facility

Building 108 is utilized at Nammo Raufoss's production facilities to produce a variety of rocket motors utilizing ammonium perchlorate (AP) based composite propellant classified as HD 1.3 energetic material. Processes conducted in the building include leakage tests, x-ray operations, painting, drying, assembly and packing. Examining Figure 3 reveals that the maximum NEQ for the entire building is 9500kg HD 1.3. However, the largest quantity present in any single room is 2800kg.

All of the materials in this building are rocket motors already in their casing without warheads. The AP based composite propellant motors do not ignite easily; they require temperatures of at least 290C for a duration of approximately seven seconds according to a Naval Research Laboratory study. Heat flux levels can be calculated to decrease as distance from the exhaust plume increases by roughly $1/d^2$ according to Boggs, Ford and Covino. Distance and orientation play an important role to prevent inadvertent ignition of adjacent motors in the event of an accident.

Based on QD methodology from DOD 4145.26-M Table AP2.T14, Building 108 requires an IBD/Passenger Traffic Route Distance (PTRD) of 55.6m and an Intraline Distance (ILD)/Aboveground Magazine Distance (IMD) of 37.7m for a NEQ equal to 9500kg. However, it is physically impossible for all 9500kg to begin burning simultaneously. A fire would take anywhere from minutes to hours to spread through the building and its spread would be hindered by installed sprinkler systems during which time personnel would be afforded time to evacuate beyond safe separation distance. An operator unlucky enough to be standing directly in the plume of a rocket motor that has been accidentally ignited would be exposed to extreme temperatures in the range of 2000°C. Such exposure would result in serious burns and/or death dependent upon the time of exposure.

Employing the QD tables from DOD Manual 4145.26-M, the QDs form a large semi-circular zone around the building. Through engineering analysis, we may be able to provide a more realistic safe separation distance in front of the light walls only as this is where any fireball or flame jet would vent from the building in a manner similar to the tests conducted by the Finnish authorities and the DDESB shown in the previous section.

NATO AASTP-1 paragraph 1.3.1.6 specifically discusses the effects of buildings with asymmetrical design such as protective roof and walls with a weak wall or door designed to provide a vent path. Directional effects from fire and projection of flame and burning debris in the direction of the weak wall will tend to focus the energy from an incident in a particular direction, hence the discussion for safe separation distances that consider such directional effects. The building being discussed here was built with such effects in mind with walls and roof made of reinforced concrete with light venting walls on one side.

Further analysis may reveal that the flame jet/fireball produced in the event of an inadvertent ignition could exceed the current IBD in the vent path, but reduce the required safe separation distance to near zero for directions other than the vent path. ***Figure 16*** below shows the current 110% IBD and IBD arcs for 9500kg HD 1.3 while the purple polygons represent the paths for ventilation from the frangible walls built into the facility.

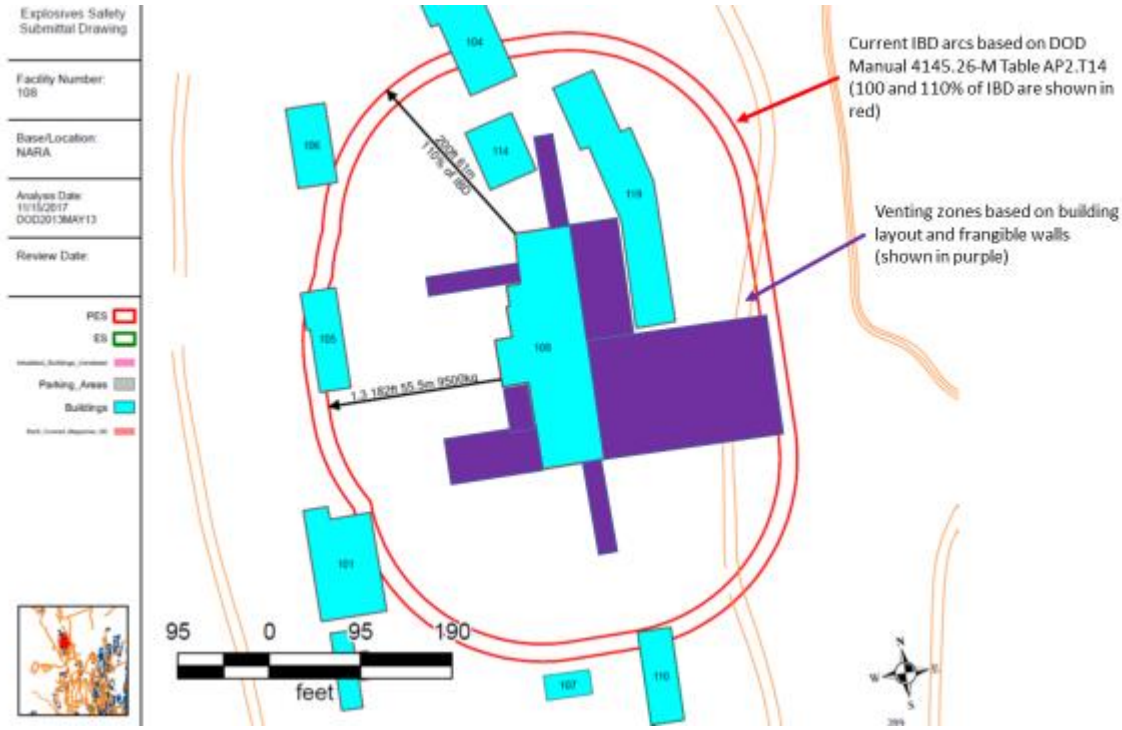


Figure 16. Example QD arcs/engineering analysis for rocket motor production building

Building 108 has vent paths shown by the purple polygons that may impact Building 119, but any flame jet or fireball will strike a reinforced concrete wall with no windows or doors. Additionally, the terrain slopes downward between the two buildings so that any flame jet or fireball from Building 108 would be directed over the roof of Building 119. Using the flame jet model from the Netherlands also states that the distance that the jet travels along the ground is approximately two-thirds of the total calculated flame jet length, further reducing the required safety zone.

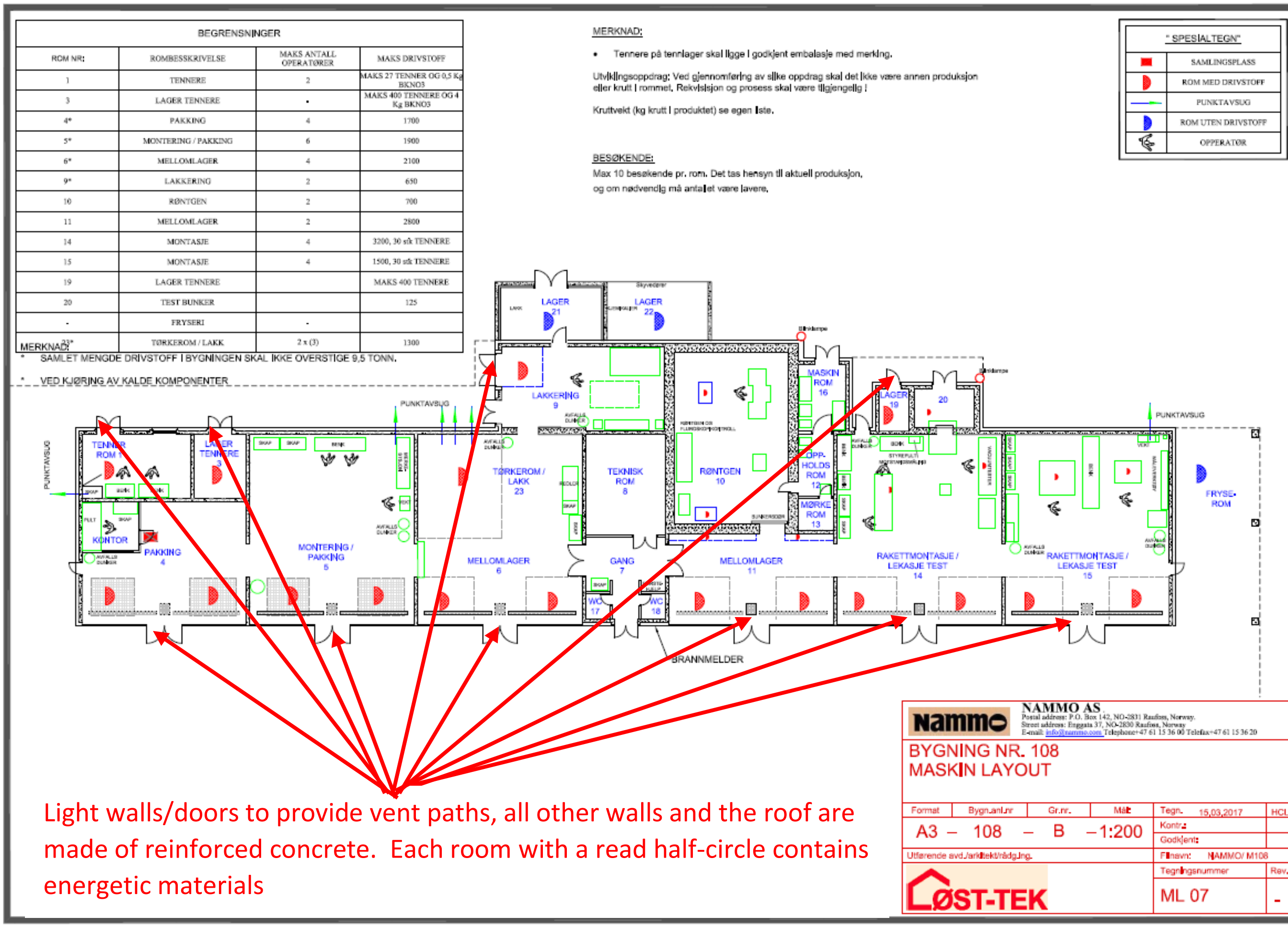


Figure 17. Rocket Motor production facility layout showing separation of operating rooms

Figure 17 shows how the production building is subdivided into smaller rooms with quantities described in ***Figure 18*** below. The values in ***Figure 18*** for flame jet length based on the model from the Netherlands and fireball diameter from DOD 6055.09-STD exceed the IBD values from Table AP2.T14 from DOD Manual 4145.26-M for the total NEW in the building and for that of each individual room.

All of the references we examined agree that fire and the resultant heat flux is the primary hazard in an HD 1.3 event, therefore we again raise the question of whether QD tables provide a comprehensive overview of the risk resulting from an accident. Using the flame jet length or fireball diameter could present a more representative hazard and augment QD calculations. When considering each room individually, the flame jet length using the model from the Netherlands results in distances less than those required when siting the building by summing all HD 1.3 materials. At the same time, the calculated fireball diameter using the calculation form DOD 6055.09-STD exceeds the IBD required by DOD Manual 4145.26-M for the two rooms with the largest individual NEWs. However, the fireball diameter includes a 20% safety factor that adds unpredictable conservatism to the results.

	HD 1.3 NEWQD	Required IBD, 4145.26-M QD value	Required ILD, 4145.26-M QD value	Calculated Flame Jet total length (length along ground: 2/3 total length) **$L = 5.49*NEQ^{0.28}$**	Calculated Fireball Diameter, **$D_{FIRE}=3.97*(NEW*1.2)^{1/3}$**
Room 4	1700	32,8	22,3	44,1 (29,4)	50,4
Room 5	1900	33,9	23,0	45,5 (30,4)	52,3
Room 6	2100	35,0	23,7	46,8 (31,2)	54,1
Room 9	650	24,7	16,7	33,7 (22,5)	36,6
Room 10	700	25,2	17,1	34,4 (23,0)	37,5
Room 11	2800	38,1	25,9	50,7 (33,8)	59,5
Room 14	3200	39,7	27,0	52,7 (35,1)	62,2
Room 15	1500	31,6	21,5	42,6 (28,4)	48,3
Room 20	125	22,9	15,2	21,3 (14,2)	21,1
Room 23	1300	30,3	20,6	40,9 (27,3)	46,1
Total	**9500**	**55,6**	**37,7**	**71,4 (47,6)**	**84,1**

Figure 18. Calculated flame jet and fireball diameter vs. QD values (all distances in meters and NEWQD in kg)

Conclusion:

Comparisons of the different equations for establishing distances show quite a large degree of variability. The authors have problems finding justification for very rigid enforcement of separation rules and the distances to the exact digits for HD 1.3 materials based purely on QD tables. While, good for a first estimate, engineering analysis should be conducted to produce a more realistic picture of the risk associated with a given quantity and type of HD 1.3 materials.

Test results indicate that packaged HD 1.3 articles can be protected from mass reactions by very small separation distances and barricades. In the Finnish test, it took over a minute and half before the adjacent container ignited with only 1.5 m of air separating the two containers. Examining the possible flame jet and heat flux associated with the fire may prove more useful than QDs based solely on weight.

For facilities manufacturing, handling or storing HD 1.3 materials, the provision of sufficient ventilation to prevent choked flow and consideration for hazard zones associated with directional flame jets/fireballs and ejected burning material are critical. Inadequate venting can result in choked flow that generates an overpressure situation resulting in debris from structures becoming a hazard for consideration in risk analysis.

Assessing the risks associated with HD 1.3 materials requires further study. Reliance purely on weight-based QD tables can lead to being both overly conservative in some cases and overconfidence in others. Studies to produce guidelines for the evaluation of heat flux and methods to relate heat flux over time, as well as taking the hazard presented by flame jets/fireballs into account would help both military and industrial organizations make better-informed risk decisions based upon realistic safe-separation distances.

References:

Boggs, Thomas L., Kevin P. Ford, and Josephine Covino. *Realistic Safe-Separation Distance Determination for Mass Fire Hazards*. China Lake, CA: Naval Air Warfare Center Weapons Division, 2013. Accessed June 1, 2018. http://www.dtic.mil/dtic/tr/fulltext/u2/a587077.pdf.

Covino, Josephine and Thomas L. Boggs. *Can We Better Address the Siting of Hazard Division 1.3 Systems*. Alexandria, VA: Policy Development Division Department of Defense Explosives Safety Board, 2010. Accessed June 1, 2018. http://www.dtic.mil/dtic/tr/fulltext/u2/a532113.pdf.

Covino, Josephine. "Hazard Division 1.3 Choked Flow Tests." Paper presented at AC/326 SC C Risk Analysis Workshop meeting, Oslo, Norway, April 2017.

Department of Defense, Undersecretary of Defense for Acquisition, Technology, and Logistics. *DOD Contractor's Safety Manual for Ammunition and Explosives, DoD 4145.26-M*. Washington, D.C., 2008.

Department of Defense, Undersecretary of Defense for Acquisition, Technology, and Logistics. *DOD Ammunition and Explosives Safety Standards, DoD 6055.09-STD, Incorporating Change 2*. Washington, D.C., 2009.

Ezekoye, Ofodike A. and Kenneth R. Diller. "A Model for Assessing Ignition, Flame Spread, and Burn Hazard Potential of a Multilayered Jacket." *Journal of Burn Care & Research*, July/August. (2006). 487-495. https://www.bme.utexas.edu/attachments/article/80/model%20for%20assessing%20ignition.pdf

Finnish Ministry of Defense. "ISO Container Propellant Ignition Tests." Paper presented by Finland at the AC/326 SG C meeting, Rome, Italy, September 2017.

North Atlantic Treaty Organization. *AASTP-1 Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives Edition B Version 1*. NATO Standardizations Office, 2015.

North Atlantic Treaty Organization. *AASTP-4 Explosives Safety Risk Analysis Part I: Guidelines for Risk-Based Decisions, Edition 1 Version 4*. NATO Standardizations Office, 2016.

North Atlantic Treaty Organization. *AASTP-4 Explosives Safety Risk Analysis Part II: Technical Background, Edition 1 Version 4*. NATO Standardizations Office, 2016.

North Atlantic Treaty Organization. *STANAG 4442 Application of Risk Analysis to the Storage and Transport of Military Ammunition and Explosives Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives*. NATO Standardizations Office, 2016.

Stolovy, Alexander, Arthur I. Namenson, and John M. Kidd. *Solid Rocket Propellant Initiation via Particle Beam Heating*. Washington, DC: Naval Research Laboratory, 1990. Accessed July 11, 2018. http://www.dtic.mil/dtic/tr/fulltext/u2/a212886.pdf.

United Nations. *International Ammunition Technical Guideline, IATG 01.50 UN explosive hazard classification system and codes, Second edition*. UN Office for Disarmament Affairs (UNODA, New York, 2015. https://unoda-web.s3-accelerate.amazonaws.com/wp-content/uploads/assets/convarms/Ammunition/IATG/docs/IATG01.50.pdf