Realistic Assessment of Hazard Division 1.3 Events

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Agenda

- Review of current QD methodology
- NATO AASTP-1 vs. US DOD 4145.26-M
- IBD comparisons from AASTP-1
- Accident and test review/comparison
- Practical implications

Current QD Methodology

- HD 1.1 and HD 1.3 based on NEWQD
- Primary hazard for HD 1.1
  - Detonation resulting in overpressure and fragmentation
  - All energetic material consumed in milliseconds
- Primary hazard for HD 1.3
  - Mass fire resulting in high levels of heat flux
  - Accidents and testing show that with adequate venting (no «choked flow»), propagation of fire takes minutes to hours
- Does weight-based QD provide a realistic assessment of the hazard from HD 1.3 materials?

Not a new idea…

- Papers sponsored by the DDESB in 2010 and 2013 discuss the shortcomings of weight-based QD for HD 1.3 materials
- Both discuss the importance of choked flow
  - Proper construction with consideration for adequate venting to prevent an event similar to detonation
- Disparities in current weight-based QD calculation methods for HD 1.3 materials…

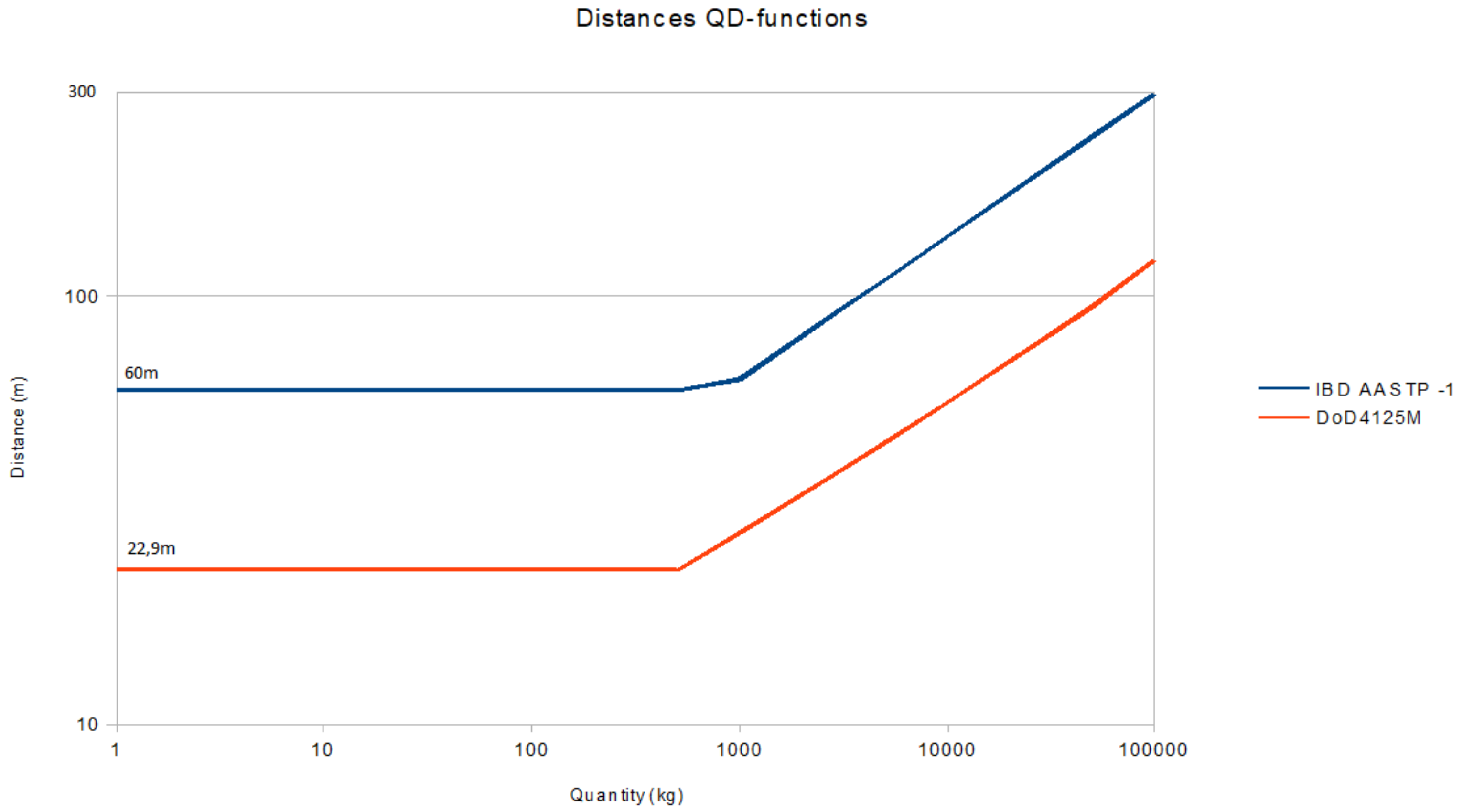
Weight-based QD does not account for...

- 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 (burns to personnel)

Subcategories of HD 1.3 within AASTP-1

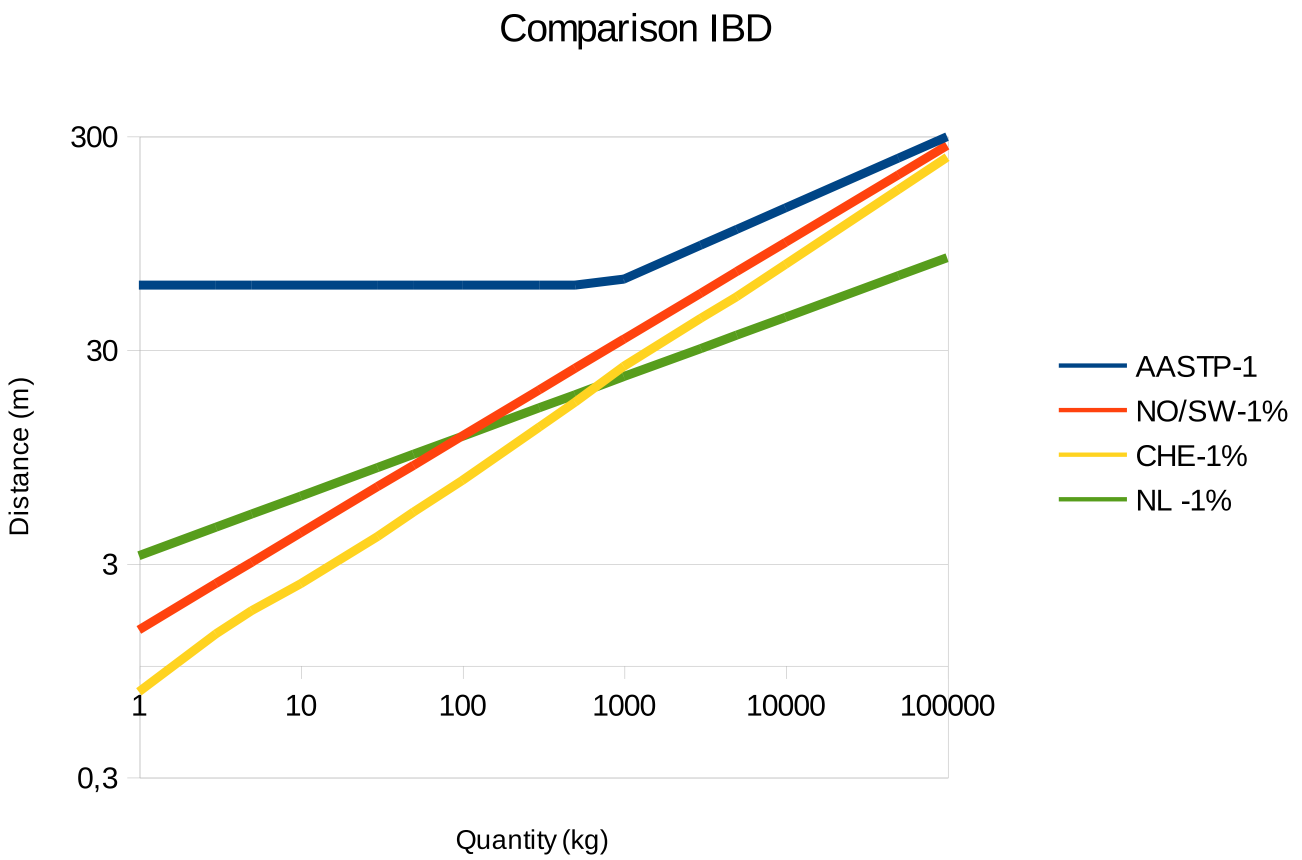
- HD 1.3.1: Explosives producing a mass fire effect
  - fireball with intense radiant heat
  - firebrands
  - some fragments where the firebrands may be massive fiery chunks of burning propellant
- HD 1.3.2: Items other than propellants that produce a moderate fire with moderate projections and firebrands
  - projections include fragments but these are less hazardous than those which characterize HD 1.2

AASTP-1 vs. DOD 4145.26-M



- Both are weight based (NEWQD)
- AASTP-1 uses cube root
- 4145.26-M uses exponential function
- AASTP-1: 41% longer QD

Disparities within AASTP-1



- Four models in AASTP-1 from NATO, Norway/Sweden, Switzerland, and the Netherlands
- Four different answers…

Accident

- 0.5 kg of black powder injured a Norwegian EOD officer due to failure to secure the fuze
  - Event occurred ~0.7m (arms length) away
- Resulted in superficial burns to his face
- Is the 60m IBD required by AASTP-1 or the 22.9m IBD required by DOD 4145.26-M warranted based on this accident?
- Black powder has a relatively low energy density (~3MJ/kg)
  - Weight-based QD does not account for the energy density of different HD 1.3 materials

Finnish Test

- Finnish Ministry of Defense tested behavior of HD 1.3 propellant in two 40-foot ISO containers
- Observed the flame jet and fireball resulting from ignition of propellant in one of the containers
- Measured the time for the contents of the second container to ignite

16 tons of HD 1.3 propellant

Fireball formation

NO-SW	SUI-Fast	SUI-Slow	NL	UK	US
88m	101	25	32	23	48
$3{,}8Q^{0{,}325}$	$4Q^{(1/3)}$	$Q^{(1/3)}$	$0{,}45Q^{0{,}44}$	$1{,}7Q^{0{,}268}$	$1{,}5Q^{0{,}36}$

Comparison of calculations for IBD and fireball diameter

- Fireball diameter prediction model calculations for 16 tons of propellant according to AASTP-4 Part II
- Again, four different answers…
- IBD for 16 tons of propellant
- Five different answers…most conservative model yields a QD 328% longer than the least conservative model

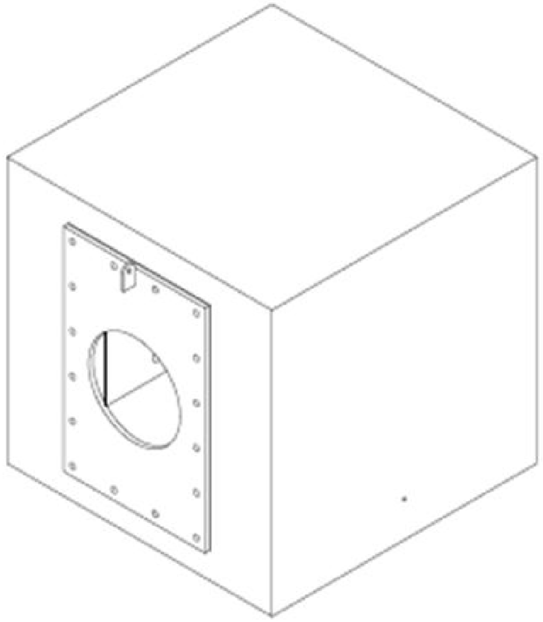
NO-SW 1% lethality	SUI 1% lethality	NL 1% lethality	US DOD 4145.26-M	NATO AASTP-1
117m	94m	49m	66m	161m

DDESB Choked flow tests

- Between 2011-2013, the DDESB conducted a series of tests to evaluate choked flow effects

Test Structure for Current Project

- Similar Construction to Kasun
  - Door modified to ensure seals and insertion of vent
    - 79 cm (vent area ratio – 0.06)
      - Unchoked Flow
    - 39 cm (vent area ratio – 0.01)
      - Choked Flow
- HD 1.3 Material
  - M1 gun propellant
    - NC
  - Large Surface Area
- 4 Tests
  - Loading Densities
    - 0.01 g/cc
      - 2 →Unchoked Flow
    - 0.05 g/cc
      - 2→Choked Flow



Fireball/flame jet calculations from AASTP-4 Part II

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

Predicted fireball and flame jet from DDESB tests, (* the range of predicted fireball diameters represents different models given in AASTP-4 part II for different reaction rates)

- Choked flow, 503kg

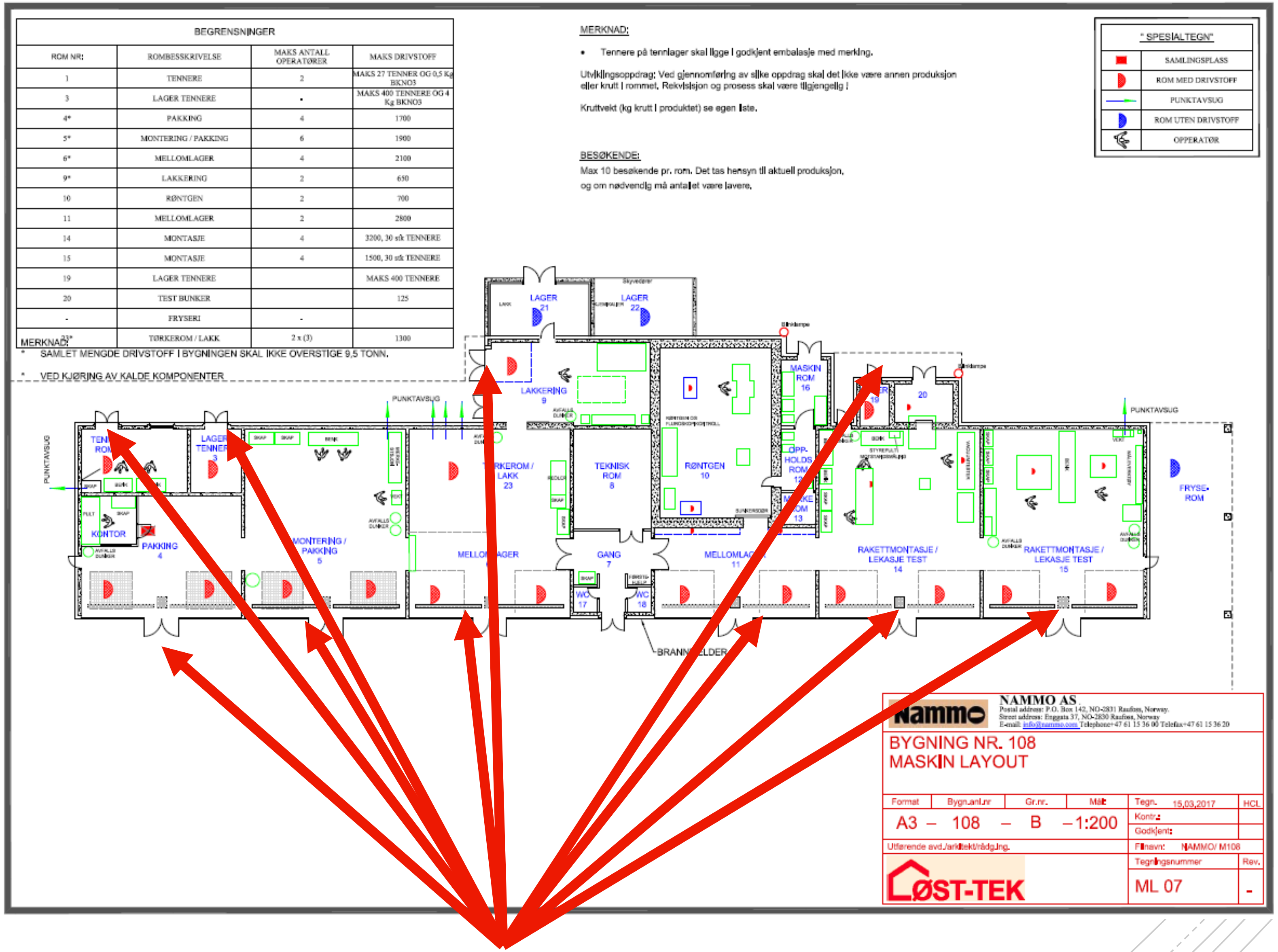
DDESB Tests

- Rupture of structure

Realistic Hazard Assessment

- Rocket motor production facility at Nammo Raufoss AS
- Building 108 is sited for 9500kg HD 1.3
- IBD with weight-based QD is 55.5m
- Building is constructed with reinforced concrete walls/roof with a light venting wall to prevent choked flow
- Building is divided into numerous rooms/cells
  - Not possible for all 9500kg to ignite simultaneously

Building 108 layout



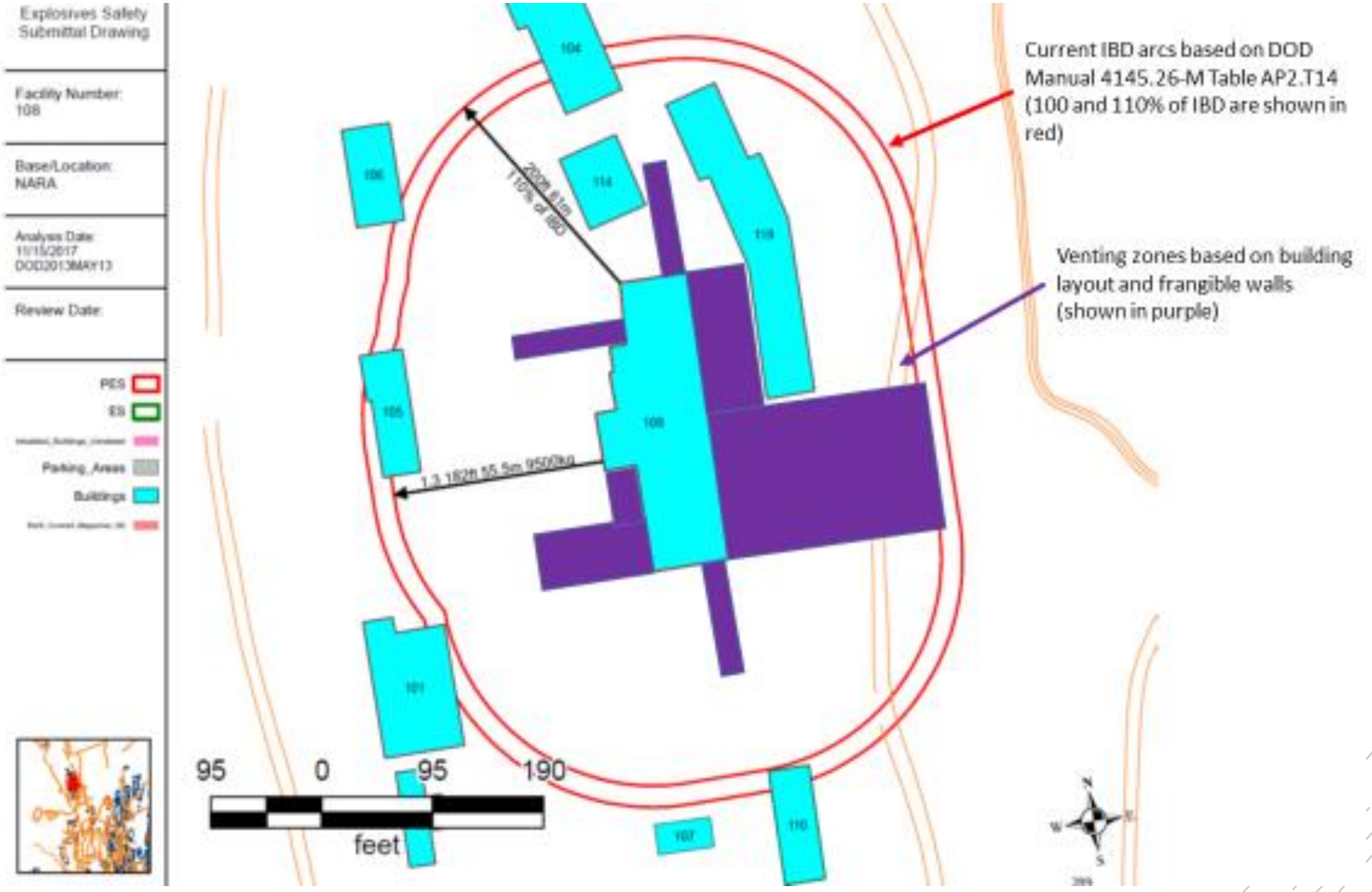
Light walls for venting in event of accident

Weight-based QD vs. flame jet and fireball calculations

	HD 1.3 NEWQD	Required IBD, 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	44,1 (29,4)	50,4
Room 5	1900	33,9	45,5 (30,4)	52,3
Room 6	2100	35,0	46,8 (31,2)	54,1
Room 9	650	24,7	33,7 (22,5)	36,6
Room 10	700	25,2	34,4 (23,0)	37,5
Room 11	2800	38,1	50,7 (33,8)	59,5
Room 14	3200	39,7	52,7 (35,1)	62,2
Room 15	1500	31,6	42,6 (28,4)	48,3
Room 20	125	22,9	21,3 (14,2)	21,1
Room 23	1300	30,3	40,9 (27,3)	46,1
Total	9500	55,6	71,4 (47,6)	84,1

Flame jet/fireball> weight-based QD

Safety zones vs. weight-based QD



AASTP-1 comments on venting

- *«A building with marked asymmetry of construction such as an igloo or building with protective roof and walls, but with one relatively weak wall or a door, induces very directional effects from the flames and the projection of burning packages.»*

- Unfortunately, there is no specific quantitative guidance in the form of calculations

Conclusions

- Comparison of QD calculation methods shows high variability
- Engineering analysis should be conducted to produce a more realistic picture of the risk associated the quantity and type of HD 1.3 materials
- Sufficient ventilation to prevent choked flow and consideration for hazard zones associated with directional flame jets/fireballs and ejected burning material is critical
- Reliance purely on weight-based QD tables can lead to being both overly conservative in some cases and overconfidence in others
- Assessing the risks associated with HD 1.3 materials requires further study