Explosion Based LUP Siting Policy for Ammonium Nitrate Sites

A paper by: Dr. Peter Harper and Mr. Dave Adams

Issue

1. HSE previously based its land use planning (LUP) advice around ammonium nitrate (AN) sites on a fire at the site producing toxic fumes of NOx. These fumes were "knocked down" in higher wind speed conditions to produce offsite risks some distance from the site.

2. There is evidence that the risks from the dispersing toxic cloud were overestimated and that the explosion risk was underestimated. This paper describes the explosion based LUP methodology for AN sites which replaces the toxics based method.

Background

3. The previous AN LUP methodology was primarily based on the risks from toxic fumes of NOx from the decomposition of AN together with other materials associated with, or stored adjacent to, the AN stacks. The methodology assumed a fire start frequency of either 10^{-2}/yr for urban locations or 10^{-3}/yr for rural locations. An event tree process was used to determine the severity of the fire which, in turn, determined the risk of dangerous dose. The methodology was coded in the SANDRA program.

4. The methodology recognised that there is the potential for the AN to detonate and generate overpressure risks. However, the SANDRA calculated likelihood of this event was usually sufficiently low that the fume risks dominated.

5. In recent years, evidence shows(1) that the amount of toxic fume generated and the hazard range from the dispersion of that fume has been overestimated previously.

6. A number of incidents involving the detonation of AN being transported on vehicles(2) further suggested that the explosion risks from AN sites (as calculated by SANDRA) may not have reflected the true likelihood of a vehicle explosion on site escalating to a full stack (or multi-stack) explosion.

Assessment Methodology

7. A project was initiated which explored the evidence for AN detonation under various conditions. The work included:

   a. Accident history
   b. Detonation of solid AN
   c. Detonation of molten AN
   d. Thermal stability of AN
   e. Influence of contaminants

f. Communication of detonation between stacks
g. Possible explosion scenarios and
h. The possibility of multi-stack explosions.

8. It was concluded that a stack of AN fertiliser which has been heated by fire and generated pools of molten AN was capable of undergoing a detonation. Further, the stack could be detonated by the prior detonation of a pool of molten AN in close proximity making this a credible route for the accidental initiation of an explosion.

9. A number of credible scenarios were proposed and the risks from these were further investigated. The scenarios in question are illustrated in Appendix 1. The scenarios were developed in an event tree format and an example is given in Appendix 2. Justification for the conditional probabilities is given in the notes associated with the event tree. “Off-spec” material is also accounted for by the use of similar event trees to those for “In-spec” material.

10. The event trees are evaluated to give cautious best estimates of the frequencies of each scenario.

11. A number of uncertainties were investigated including:

    a. Building fire probability
    b. Vehicle fire probability
    c. Detonation probability following vehicle fires
    d. Stack detonation probability
    e. Influence of pallets
    f. Influence of urea presence
    g. Detonation of molten AN and
    h. Probability that AN will fail a Detonation Resistance Test.

12. These uncertainties were investigated by adjusting the conditional probabilities in the relevant event tree and new overall frequencies determined.

13. The work was subject to internal review by a retired expert in energetic substances previously employed as a Principal Scientist at HSL. This review contained a number of comments and suggestions for alternative values for some of the conditional probabilities. The suggested changes were such that only the values for bulk sites co-storing urea were affected.

14. It was recognised that, before the proposed methodology could be adopted, the work required independent peer review. Three organisations were identified who had the appropriate mix of academic and industrial knowledge to carry out these reviews.

15. The reviews raised a number of issues which would affect the consequences and likelihoods of the various scenarios.

16. HSE accepted a number of the suggested changes to frequencies and conditional probabilities put forward by the independent reviewers. This created an updated version of the values used to determine LUP zones.

Application of the Methodology

17. A number of example cases were used to test the likely overall site event frequencies based on the event tree calculations. These cases were intended to cover the range of likely sites that would require consent and included:
    a. TC1: Blending plant – Inside storage – No consent restriction on urea storage
    b. TC2: Blending plant – Inside storage – Urea storage prohibited by condition on consent
    c. TC6: Bagged storage – Inside (no blending or repacking)
    d. TC8: Bagged storage – Outside (no inside storage, blending or repacking)

18. The relevant sub-event trees are evaluated to give overall sub-event frequencies for the test cases. The sub-event frequencies for TC1 based on the "best estimate" are given in Appendix 3. The frequencies from similar sub-events are summed to give the overall frequency for an event with a particular consequence. For example, the frequencies of all the sub-events that can lead to a single bulk stack explosion are summed to give the overall frequency of this event.

19. These overall frequencies can be used together with the protection concept based methodology developed by HSE to determine the appropriate representative worst case event on which to base the LUP zones for the site represented by each test case. The criteria used are given in Appendix 4.

20. A spreadsheet was developed to represent the calculations in an **A**mmonium **N**itrate **E**xplosio**N** **O**verpressure **ME**thodology and is entitled ANENOME.

21. ANENOME is based on a number of assumptions:
    a. Severe building fire frequency is taken from work by Harman(3) who assumed an average storage of AN for 6 months/yr. Storage for 12 months results in a 50% increase in frequency. Storage for 3 months results in a 66% reduction in frequency;
    b. Each building or storage area is assessed separately;
    c. Warehouses storing bagged material do not normally include bagging plants;
    d. Buildings have "average" fire protection (Harman assumption). Additional fire protection may result in a reduction in building fire frequency by a factor of 2;
    e. Poor site conditions (limited fire suppression, urban location, etc) can cause an increase in fire frequency (by a factor of 2);
    f. Flat bed trucks, dumper trucks and bagging plants have AN "loads" of approximately 25 te;
    g. Flat bed truck and dumper truck fire frequencies are scaled by site throughput, relative to an assumed throughput of 10,000 te/yr;

h. In the absence of site specific information, it is assumed that site throughput is twice that of the consented quantity.

22. The methodology is illustrated in Appendix 5. Note that all overpressure events take account of damage to buildings causing harm to the buildings' occupants. The level of building damage is related to the pressure exerted on the building by the explosion. HSE uses an overpressure of 600 mbar to determine the distance at which damage is sufficient to expose the occupants to a significant risk of fatality (or Risk of Death (ROD)). 140 mbar is used to determine the risk of dangerous dose (RDD) to a normal population and 70 mbar is used to determine the risk of dangerous dose to a sensitive population (SDD).

23. From the above, the risks determined are to indoor populations. HSE assumes that people are indoors 90% of the time during the day and 99% of the time at night.

24. It can be seen from Appendix 5 that, in this example, the only events with sufficient frequency to set an inner zone are the small explosion (i.e. 25 te from dumper truck explosion or bagging plant explosion). The frequency of the small explosion event is sufficient to set a Risk of Death (ROD) based inner zone based on the distance to an overpressure of 600 mbar (63m). The inner zone would be set at 65m (63m rounded to nearest 5m).

25. For the middle zone, there are 2 events which have sufficient frequency. These are:

    a. Small explosion

    b. Single stack (bulk)

26. The stack event gave the greatest hazard range (216m) based on ROD.

27. For the outer zone, a similar process is used to determine that a single stack would have the greatest hazard range (538m) based on risk of DD.

28. The above analysis gives LUP zone distances of 65, 215 and 540 m for a site with bulk storage but without restrictions on co-storage of urea.

Implications

29. The extent of the zones for a specific site storing AN would depend on:

    a. Site throughput
    b. Heap size for bulk AN (if relevant)
    c. Bagged stack size
    d. Truck load size
    e. Number of buildings storing/handling loose AN (if relevant)
    f. Number of buildings storing bagged AN
    g. Presence of outdoor storage of bagged AN
    h. Proportion of the year that AN is handled/stored
    i. The presence of additional fire precautions
    j. Co-storage of urea

30. For bagged storage sites where the site throughput is low (less than approx. 4000 te/yr), the ANENOME methodology does not result in a

high enough risk to generate an Inner Zone. It is recognised that there may still be a toxic element from the fire events which may produce an IZ of approximately 60-70m. It would be sensible to set a minimum IZ distance of 65m for all AN sites irrespective of throughput.

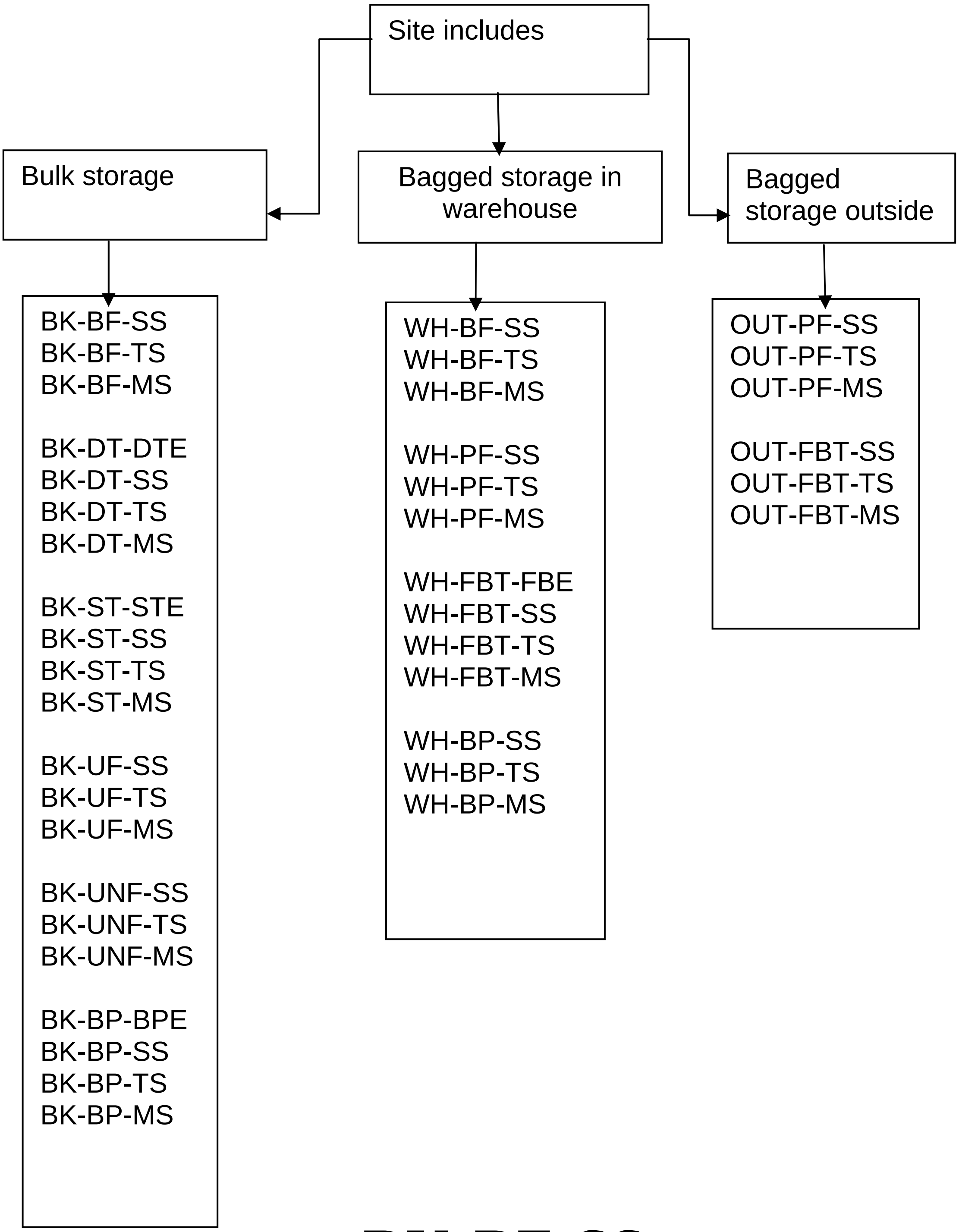
References

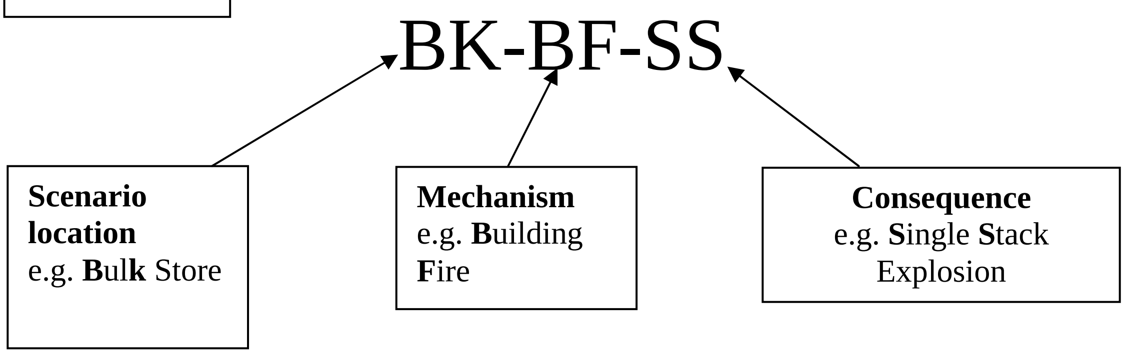
(1) Atkinson G and Adams W D, Ammonium Nitrate: Toxic Fume Risk from Fires in Storage, International Fertiliser Society Proceedings No 496., 3rd October 2002 (TRIM 2007/322910)

(2) Safety and Security Issues Relating to Low Capacity Storage of AN-based Fertilizers, Marlair G. and Kordek M., Journal of Hazardous Materials, A123 (2005) 13-28

(3) Harman, N.F. (1997) “Review of Ammonium Nitrate Warehouse Fire Frequency” AEA Report AEA/25106001/R/1.

APPENDIX 1: List of Scenarios Included in Risk Assessment





Abbreviations used in scenario descriptors:

Scenario locations:

BK	**Bulk storage**
WH	**Warehouse storage of (big) bagged material**
OUT	**Outside storage of (big) bagged material**

Mechanisms:

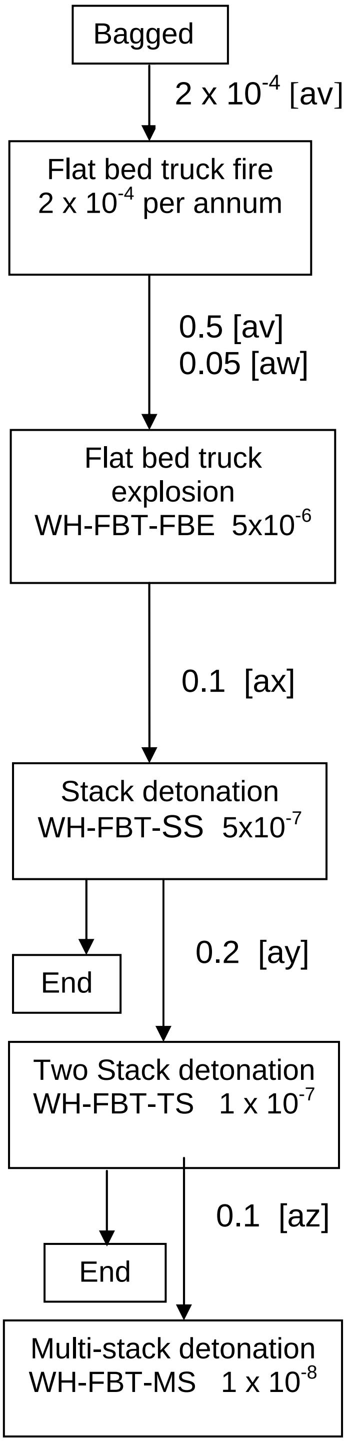
BF	**Building fire**
DT	**Dumper truck fire**
ST	**Shovel truck fire**
UF	**AN/Urea co-storage – Fire**
UNF	**AN/Urea co-storage – Non-fire reaction**
BP	**Bagging/blending plant fire**
FBT	**Flat bed truck fire**
PF	**Pallet layer fire (under bagged stack)**

Consequences:

SS	**Single stack explosion**
TS	**Two stack explosion**
MS	**Multi-stack explosion**
DTE	**Dumper truck explosion**
STE	**Shovel truck explosion**
BPE	**Bagging/blending plant explosion**
FBE	**Flat bed truck explosion**

Appendix 2: Example Event Tree with Conditional Probability Justification

WAREHOUSE STORAGE – FLAT BED TRUCK FIRE SCENARIOS



[av] This figure is based on Department of Transport figures for the rate of lorry fires (per mile). Assuming an average speed of 30 mph gives a figure of 3×10^{-6} fires per hour of operation. DOT statistics include fires as a result of high speed collisions which are unlikely during the unloading of AN to a bulk stack. Other common causes of fire such as electrical faults, tyre pickup and brake overheating are possible. Since (in contrast to the dumper truck) many flat bed trucks will not arrive on the site in a loaded state, it is assumed that the probability of fire when loaded is reduced to 1×10^{-6} $hour^{-1}$.
It is further assumed that sites have a throughput of 10,000 t per annum (corresponding to approximately 400 loads) and that each truck will remain on the site for 30 minutes in a loaded or almost loaded state. This gives a total fire start frequency for loaded trucks of 2×10^{-4} per annum. It is assumed that the probability that a given Flat Bed Truck will be parked close to a stack is 0.5. This leads to a final figure for the rate of loaded FB truck fires of close to bagged stack 1×10^{-4} pa.

[aw] The best estimate for the probability of detonation of a loaded flat bed truck carrying AN during a lorry fire is 5%. This is based on a comparison of the number of detonations and an estimate of the total number of fires in trucks carrying AN over an equivalent period.
During a fire in a flatbed truck carrying AN the load is normally spilled at an early stage as bags start to fail. AN piles up around the tyres, axles and fuel tank and there is substantial and prolonged contact between AN and combustible materials. Large quantities of potentially heavily contaminated molten AN are produced.

[ax] Truck detonations produce a range of hot fragments with high KE. Work by Bauer and Van Dolah suggests that these may cause stack detonation.

[ay]] In the case of bulk scenarios where there has been no general fire prior to initiation (e.g. WH-FBT-SS) it is likely that separation between adjacent stacks will have been preserved at the time of any initiation; giving a relatively low chance of communication of detonation to a second stack. It is possible, however, that a truck may be parked close enough for a fire to affect two bagged stacks directly and a higher probability (than bulk) of double bagged stack detonation is used. The probability of propagation of detonation would be higher if materials were off-spec. This is dealt with in a separate scheme

[az] More stacks can in principle become involved – with rapidly decreasing probability. The probability of further propagation of detonation is higher if material is off-spec. This is dealt with in a separate scheme

Appendix 3: Individual and Overall Event Probabilities for Test Case TC1

				Throughput	
Events	Inventory	Base Frequency		10000	
			Total	Freq	Total Freq
TC1					
STE	5	2.00E-07		2.00E-07	0.200
DTE	25	4.00E-07		4.00E-07	
BPE (BK or WH)	25	6.00E-06	6.400	6.00E-06	6.400
BK-BF-SS	Stack Size	2.00E-08		2.00E-08	
BK-DT-SS	Stack Size	4.00E-08		4.00E-08	
BK-ST-SS	Stack Size	2.00E-08		2.00E-08	
BK-UF-SS	Stack Size	2.00E-07		2.00E-07	
BK-UNF-SS	Stack Size	3.00E-07		3.00E-07	
BK-BP-SS	Stack Size	7.00E-08	0.650	7.00E-08	0.650
BK-BF-TS	2 x Stack Size	3.00E-09		3.00E-09	
BK-DT-TS	2 x Stack Size	5.00E-09		5.00E-09	
BK-ST-TS	2 x Stack Size	2.00E-09		2.00E-09	
BK-UF-TS	2 x Stack Size	4.00E-08		4.00E-08	
BK-UNF-TS	2 x Stack Size	3.00E-08		3.00E-08	
BK-BP-TS	2 x Stack Size	8.00E-09	0.088	8.00E-09	0.088
BK-BF-MS	5 x Stack Size	6.00E-10		6.00E-10	
BK-DT-MS	5 x Stack Size	5.00E-10		5.00E-10	
BK-ST-MS	5 x Stack Size	3.00E-10		3.00E-10	
BK-UF-MS	5 x Stack Size	8.00E-09		8.00E-09	
BK-UNF-MS	5 x Stack Size	3.00E-09		3.00E-09	
BK-BP-MS	5 x Stack Size	1.00E-09	0.013	1.00E-09	0.013

Appendix 4: Criteria for adoption in the matrix are used

Zone	**Criteria**
Inner	Frequency >=10 with indoor or outdoor dangerous dose (DD) Frequency >=3 with indoor or outdoor risk of death (ROD)
Middle	Frequency >=1 with indoor or outdoor dangerous dose (DD) Frequency >=0.3 with indoor or outdoor risk of death (ROD)
Outer	Frequency >=1 with indoor or outdoor sensitive dose (SensDD) Frequency >=0.3 with indoor or outdoor dangerous dose (DD) Frequency >=0.1 with indoor or outdoor risk of death (ROD)

Appendix 5: Protection Concept Based LUP Zones for TC1

TC1 Blending and bagging, urea unrestricted											
	Event	Freq (cpm)	Inventory	Basis	600 mbar	140 mbar	70 mbar				
IZ	DTE or BPE	6.40	25	ROD	63						
	SS (Heap)	0.65	1000	Not Sig.							
	TS (Heap)	0.09	2000	Not Sig.							
	MS (Heap)	0.01	5000	Not Sig.							63
MZ	DTE or FBE or BPE	6.40	25	DD		157					
	SS (Heap)	0.65	1000	ROD	216						
	TS (Heap)	0.09	2000	Not Sig.							
	MS (Heap)	0.01	5000	Not Sig.							216
OZ	DTE or FBE or BPE	6.40	25	SensDD			269				
	SS (Heap)	0.65	1000	DD		538					
	TS (Heap)	0.09	2000	Not Sig.							
	MS (Heap)	0.01	5000	Not Sig.							538