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THE STORAGE OF BOMBS IN ALL-UP CONDITION

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ABSTRACT

With the changing role of UK forces and, in particular, with reference to the Royal Air Force role in the Rapid Reaction Force, the logistic requirements for bomb storage are changing. Bombs may, in future, be stored in all-up condition, ie with fuses, fins etc assembled, and will be stored in all-up round containers (AURCs). They may also be stored in ISO containers. These changes of storage policy have repercussions in the ESTC rules governing the storage of bombs. In this paper the currently available test information regarding the effects of inter-stack stand-off, orientation, stacking height and traversing is reviewed and analyzed in the light of these new requirements. ISO container storage is not considered. Recommendations are made on the precautions to be taken to avoid inter-stack propagation in the event of the accidental initiation of one stack.

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INTRODUCTION

1.   The UK conditions for the storage of HE bombs have, to date been those prescribed in ESTC Leaflet No.5, Part 2 (see Annex A). Although it is not stated, the prescription relates to the storage of iron bombs without fuses, fins etc and with the fuse wells protected with robust plugs. That is to say that the bombs must not contain explosives other than the main filling and, possibly, the booster explosive. There must also be adequate all round protection from attack by shock or fragments from a nearby donor explosive event. The requirement, when D1 conditions apply, for a stack height no greater than one metre has effectively prevented stacking of bombs.

2.   With the changing roles of the RAF and in particular with reference to their role in the Rapid Reaction Forces, tactical and logistic requirements for the storage of bombs are changing. The RAF now requires (Reference 1) that bombs should be stored in an all-up condition ready for use in All Up Round Containers (AURCs). The AURCs may be required ultimately to be stored in ISO Containers. This change of storage concept presents three major problems in terms of the current ESTC prescription:

   a.   Bombs must be stored with fuses in place.

   b.   With the use of AURCs the separation distance between bombs is increased and the density of bombs (bombs per unit storage area) achieved under current single layer conditions can only be equalled by stacking.

   c.   Storage of bombs in ISO containers has never been considered and the consequences of an accidental initiation both in terms of donor and acceptor effects may be different.

3.   In Reference 2, the RAF have prioritised their requirement for advice on future bomb storage. It is the purpose of this paper, in line with their priorities, to address problems a. and b. above.

4.   A survey has been made of the information available on sympathetic reactions between bomb stacks. From the analysis of the amassed data it is concluded that, given control is maintained over the orientation and disposition of stacks of bombs, storage of bombs in their AURCs with fuses, fins etc attached is feasible within existing seperation distances and without compromise to current safety levels.

LITERATURE SURVEY

1945 Tests at Wingate Ordnance depot, USA (Reference 3).

5.   A series of tests were carried out between 23 May 1945 and 5 June 1945 "to determine the minimum safe distances at which pads of 150lb G. P. T-I bombs without

boosters might be stored without danger of the detonation of one pad propagating to an adjacent pad". The results are summarised in Table 1 and the conclusions drawn at the time were as follows:

a. When these bombs are stored one bomb high and nine bombs wide and placed nose to tail within each pad, 25,000 or 50,000 pounds of explosives may be safely placed in pads spaced 100ft apart.

b. The tail of these bombs is the most dangerous part as regards adjacent piles because the missiles produced are much heavier resulting in numerous penetrations of adjacent bomb cases, while no such effects were observed from the nose.

c. When the bombs are stored one bomb high and nine bombs wide and with the noses of four rows facing in one direction and the noses of the other five rows facing in the opposite direction so that only the noses of bombs face towards adjacent pads, the safe distance between pads may be reduced to 50 feet for 25000 pounds of explosive per pad.

d. When the bombs are placed as in a. or c. above, the debris from the their detonation will be generally within the area enclosed by the prolongation of the sides of the pad and with little or no debris off the corners of the pad."

6. It has to be emphasised that these conclusions relate to a single layer carpet of bombs filled with TNT, normally a relatively insensitive explosive. There is some indication that the fillings of the bombs used in the tests had become sensitised in some way in that "there had been fourteen instances in which the bombs had exploded low order from slight bumps received in normal handling, and were considered too dangerous for further use".

1946 ESTC Soltau Trials (Reference 4)

7. In 1946 the ESTC were requested by the Air Ministry to "express an opinion as to the safety from propagation of the standard operational supply dumps laid out on an aerodrome". A series of trials was designed to investigate the possibility of propagation between typical bomb dump arrangements both with and without traverses. The results of these trials are summarised in Table 2.

8. The conclusions drawn are as follows:

a. By comparison with US trials in which there were no traverses, eg Reference 3, propagation is caused by fragment attack and not by air blast or shock.

b. Fragment induced propagation can be prevented by the use of simple earth

traverses which must be higher than the stacked ammunition.

c.   The use of empty bomb cases in lieu of an earth traverse was unsuccessful.

d.   It has been shown, albeit in only one test, that reaction is not propagated between earth traversed stacks of 36000kg NEQ separated by 11m ($0.33Q^{1/3}$ or nearly D1 distance).

e.   Stacks three or four tiers high can be adequately isolated using traverses designed in accordance with ESTC prescriptions.

1947 ESTC Dune and Heligoland Trials (Reference 5)

9.   These trials were, in essence, a continuation of the Soltau trials. They were designed to test the likelihood of communication between untraversed bomb stacks in the standard Air Ministry spacing of 125yds and also at 250yds. The results of the trials are summarised in Table 3.

10.   It was concluded that, to guarantee non-propagation between stacks of bombs in the geometries used, spacings greater than 228m must be used. It is, however, interesting to note that, in the final firing where there was no acceptor in direct line with the axes of the donor bombs, no reaction occurred. It begs the question, would the same be the case at shorter ranges.

1967 BIG PAPA High Explosives Storage Tests (Reference 6)

11.   A programme of trials was designed by a USAF special study group, tasked in September 1966 to determine, based on existing information, if existing bomb storage quantity-distance criteria could be reduced. Such reductions were sought as real estate for bomb storage was insufficient. The need for these trials was confirmed by a Munitions Safety Assessment Team in late September 1966. The tests were to represent standard barricaded field storage conditions using 250,000lbs donor charges and acceptors of 100,000lbs at "K1.1 distances"($0.43Q^{1/3}$ in metric units). The results of the trials are summarised in Table 4.

12.   Among the conclusions reached were:

a. "A substantial reduction can be made in the current Department of Defense (DoD) barricaded above ground intermagazine quantity-distance criteria for mass-detonating explosives in open storage (revetments without structures that would burn or create heavy falling weights or damaging secondary fragments).

b. Bombs located at K1.1 (imperial units) or less from the donor explosions will be covered with earth and unavailable for use until extensive uncovering operations are completed. Bombs at K2.5 (imperial units), ($0.99Q^{1/3}$ in metric units) separations will be readily accessible.

c. The modular concept developed by the Air Force Special Study Group and approved for use in combat zones is sound for large quantity munitions storage. A module consists of five cells separated from one another by intermediate barricades.

d. The minimum barricaded distance between single stacks of mass-detonating explosives stored in adjacent cells of a module could be based on a K-factor of 1.1 ($0.43Q^{1/3}$) with a high degree of confidence.......

e. ....the spacing between modules could be based on a K factor of 2.5 ($0.99Q^{1/3}$) related to the net weight of explosive in one cell rather than that of the whole module.

f. The recommended NEW for one cell of 100,000lbs can be increased to 250,000lbs provided that the spacing corresponding to K1.1 ($0.43Q^{1/3}$) is maintained.

g. Since no sympathetic simultaneous or delayed detonations occurred the number of cells per module may be considered arbitrary.

13.   Revised quantity-distance criteria established within the USAF were included in the USAF Explosives Safety Manual in February 1968.

1985 Suppression of Propagation Between Stacks of Bombs (Reference 7)

14.   This programme of tests, carried out in 1985 and 1986, was designed to investigate the use of inert buffer materials between stacks of Mk82 and Mk84 bombs. The buffer materials were limited to those inert materials which are required to be stored at or near bomb storage areas. In addition the effects of the orientation of bombs, ie nose to tail, nose to nose etc. were investigated. The results are summarised in Tables 5 and 6.

15.   They conclude that "propagation between stacks of MK82 or MK84 bombs can be prevented when they are properly oriented, separated, steel nose and tail fuse well protection is provided and buffer material proven adequate in this test series is used".

16.   In open stack storage situations they have shown that, even at as little as 15ft separation, by orienting the bombs in nose to nose arrays, given that the fuse wells are protected, acceptor reaction is prevented. However bombs in the acceptor stacks are

damaged by fragment attack.

DISCUSSION

Effects of storage with fuses fitted.

17.   Limited information exists regarding the stack to stack reaction between bombs fitted with fuses. In four of the tests of buffered Mk82 bombs (Table 5), acceptors were fitted with fuses and booster explosives. These showed that, given an inert barrier between stacks, there was no reaction in the N(ose)→T(ail) donor→acceptor orientation and a minor reaction in the T→N direction. The N→N orientation was tested twice and on neither occasion was there any reaction. This same performance in the N→N orientation could be emulated by the insertion of a steel rod into the bomb fuse cavities. With plastics rods in the fuse wells, full detonations occurred in N→T and T→N orientations.

18.   Furthermore in tests with MK84 bomb stacks (Table 6) with no barrier at 4.57m (0.21$Q^{1/3}$) separation, in the N→N orientation there were no events in four tests whereas in any other orientation (3 tests each N→T and T→N, 2 each with inert barriers) there were events ranging from partial events to full detonations. In the N→N cases there was fragment damage and erosion of the noses of the bombs.

19.   Thus, given that the fuse complies with the necessary safing and arming standards, and the stacks of bombs are directed nose to nose there should be little chance of propagation between stacks separated by at least 0.21$Q^{1/3}$. However the number of tests carried out was small and the confidence in a high probability that propagation will not occur cannot be high. Therefore, for additional protection the introduction of traverses to intercept primary fragments between stacks (see paras 24 et seq) will prevent high velocity fragment attack on acceptor bombs.

Effects of stacking bombs more than one tier high.

20.   In all the trials summarised above, with the exception of the 1945 Wingate Trials, bombs were stacked more than one tier high. In the trials used above to support the conditions for storage of ready fused bombs, Mk 82 500lb bombs were stacked two high and Mk 84 2000lb bombs three high. In the Wingate Trials (Table 1) it will be seen that similar N→N results were achieved between single layer stacks albeit at longer ranges (>15.24m or 0.68$Q^{1/3}$). In these same trials there were occasions at the same separation when N→T or T→N oriented stacks did not interact).

21.   Thus, as might be expected, increasing the stack height will increase the probability for interaction in the N→T and T→N and indeed the S(ide)→S(ide) orientations as the target presented to the fragments from the donor is much greater. However, by adopting the N→N orientation where the number of donor fragments is small and the individual bomb

presented area is small and obliquely angled, this increased fragment attack "cross-section" can be overcome and the probability of propagation between stacks significantly reduced.

Effects of packaging bombs in AURCs and on pallets.

22.   The packaging of bombs in AURCs effectively separates the bombs from one another both within the AURC and between AURCs. This separation is not so effectively achieved when bombs are strapped to pallets as, on any one pallet the bombs are held in close contact with each other.

23.   It is known that, when shell or bombs are initiated in close contact with each other, a reaction zone is generated between the munitions within which fragments of much higher velocity and density can be generated (Reference 8). By separating the munitions even by a fraction of one charge diameter it is believed that this effect can be diminished. Therefore the use of AURCs, or to a lesser extent palletisation may have the advantage of reducing these enhanced fragmentation effects and thus reducing the chance of propagation.

The effects of barricades/traverses

24.   It has been shown above that the probability of inter-stack propagation can be markedly reduced, in particular, by appropriately orienting the bombs within stacks relative to one another. However, to ensure that the probability of fragment initiated propagation is reduced to the absolute minimum, the fragments must be prevented from arriving at the acceptor stack, or, if they do arrive, they should have insufficient energy to stimulate a reaction in the acceptor bombs. A number of types of barricade have been tested in the trials surveyed:

> a. Simple earth traverses were used in many of the tests (see Tables 2 & 4). These were typically 1:2 sloped compacted local earth with a 0.91m wide top. They extended above the height of the bomb stacks by at least 0.66m. They comply with the ESTC requirements for Standard Double Slope Traverses.

> b. Various stacks of inert components or small calibre ammunition (Tables 2 & 5).

> c. 55 gallon oil drums (Table 6)

> d. Metal bins of various designs, earth filled (Reference 6).

> e. Soil/cement mixture traverses allowing steep (3:1) sides with 0.91m minimum thickness (Reference 6).

25.   Simple earth traverses were shown to be very effective. In 12 out of the 14 tests carried out acceptor bombs were all undamaged though covered in the earth displaced from the traverse. In the remaining two tests low order events occurred, one where a 750lb bomb was pinched between the two broken halves of the concrete ground slab and the other where a 750lb bomb had fallen from the top of the stack and was then crushed by a 2000lb bomb. There was no evidence of any interaction between these bombs and those around them.

26.   The protection provided by stacks of inert components, small calibre ammunition and oil drums was very variable and highly dependent on the orientation and disposition of the stacks. For example, in one test, (Table 5), a barricade of one row of CBU58s, cluster bombs classified HD 1.2, resulted in a low order event in the acceptor and on two occasions a two row barricade of the same munitions resulted in full detonation of the acceptor. It is unlikely that any general rules for this type of barricade can be deduced owing to the dependence on the specific nature, geometry, stacking etc of the barrier components.

27.   In the trials in which metal bin and soil/cement traverses were tested, live acceptor charges were not used. It is not, therefore, possible to comment on their efficiency in preventing propagation. However, it was found that, in the case of the metal bin barriers, components of the bins themselves became a hazard in that they were thrown upwards of 250m, in one case steel sections were found 460m away. The soil/cement traverse behaved much like earth traverses. Some larger lumps of the soil/cement matrix were thrown around 10m, the rest breaking down and covering the area beyond the traverse to about 0.9m depth. A paper on related barrier designs is presented elsewhere in this Seminar.

28.   Whilst no trials evidence has been presented here there is growing opinion that barriers of water will be very effective in preventing propagation between stacks. If this is considered an attractive proposition from the user's point of view it could be further investigated.

Maximum NEQ per stack

29.   Given that the precautions so far described (use of earth traverses, appropriate bomb orientations and seperations) are taken, the "Big Papa" trials (Table 4) showed that propagation could be prevented with donor charges up to 113400kg at separation distances down to 15.2m $(0.31Q^{1/3})$. The donor charge layout in these tests was four rows of bombs four tiers high, the overall stack dimensions being 12.2m x 9.1m x 2.7m high. There is no reason to suppose that the extension of the stack in the long dimension with appropriate extension of the traverses should increase the likelihood of propagation. Therefore the total NEQ in any one stack could, potentially be much greater than 100,000kg. The important consideration should, therefore be the number of munitions that can economically or tactically be put at risk in any one stack.

Size of bombs

30.   Whilst the evidence presented above brackets but does not specifically include tests on 1000lb bombs, there is nothing to indicate that, unless bomb case thicknesses and materials are markedly different, the effects and reactions from stacks of both smaller and larger bombs should not be relevant to 1000lb bombs. Traverses, given that they are of sufficient height relative to the stack heights, along with stacking orientation controls, will ensure that fragment initiation of acceptors will not occur. Shock wave initiation of acceptors without fuses from donors as close as $0.31Q^{1/3}$ for NEQs of 113400kg does not occur (Table 4). For smaller NEQs up to 8816kg, including bombs fitted with type 904 and 905 fuses, (Table 6), no shock interaction, either air or ground transmitted, has been observed as close as $0.21Q^{1/3}$. Again, unless there are marked design differences in the 1000lb bombs or in the robustness of the fuses, this data will read across to those bombs.

The effects of different explosive fills.

31.   Given that the acceptor bombs are protected from the donors by a traverse, the acceptors will only be vulnerable to air or ground transmitted shock. Ignoring secondary effects, eg the bomb pinched between segments of a concrete pad lifted by ground shock (Reference 6), the susceptibility of the bombs will be very much a function of the shock sensitivity of their fillings. In Table 7 (extracted from Reference 9) Large Scale Gap Test results are given for the explosives used in the various test programmes. The most sensitive, Pentolite, filled bombs were used in the Soltau tests to address the problem of shock interaction between stacks. At $0.33Q^{1/3}$ there was no reaction in the acceptor stack. In the Buffered Bomb tests some bombs contained booster explosives whose Gap test energies would be between 1GPa and 2GPa. Again no acceptor reactions were observed which could be related to an air or ground shock interaction.

CONCLUSIONS

32.   The storage of stacks of 1000lb bombs in an all-up condition complete with fuses and tail fins etc will not adversely effect their vulnerability to shock from the accidental initiation of neighbouring stacks of bombs provided that the conditions currently laid down in ESTC Leaflet 5 Part 2 for the storage of unfused bombs. The insertion of the fuses into their fuse wells may reduce the vulnerability of acceptor stacks relative to that of unfused or lightly capped bombs (paras 17 et seq) when donor and acceptor bombs are oriented nose-to-nose.

33.   Stacking of bombs in their AURCs to a height of 3 tiers is acceptable as long as the earth traversing is increased in height commensurate with the height of the stack of bombs and in accordance with ESTC prescriptions. Nose to nose orientation between bombs in adjacent stacks will further reduce the probability of interaction (paras 20,21) and the separation provided by the packaging may reduce the fragment hazard from the donor.

34.   Whilst earth traverses built to ESTC prescriptions perform well in preventing the fragment attack of acceptor stacks, the effectiveness of inert munition component or small calibre ammunition barriers is highly dependent on the specific components and their stacking arrangements and it is thus impossible to generate generic prescriptions for their use. Some guidance has been given in NATO Manual AASTP-1 (Reference 10) on specific arrangements found to be effective.

35.   Stack size need only be limited by consideration of the maximum acceptable losses that will be incurred in the event of an accidental initiation of an individual stack and the normal IBD considerations calculated on the basis of the maximum credible event being a single stack.

36.   Given that there is no major excursion from the traditional iron bomb case design principals, the above conclusions are independent of the size of the individual bombs.

37.   Propagation by ground or air shock will not occur given that the main charge filling or booster explosives have Large Scale Gap Test sensitivity results in excess of 1GPa.

RECOMMENDATIONS

38.   That ESTC Standards be amended to include the storage of all-up bombs either palletised or in all up round containers within current advice for the storage of unfused bombs subject to the restrictions specified below.

39.   Bombs stored either on pallets or in their AURCs are to be stacked no more than 3 tiers high.

40.   Double slope earth traversing in accordance ESTC Standards is to be installed between stacks.

41.   That the outside rows of bombs in any one stack are oriented such that they are nose-to-nose with the bombs in the outer rows of adjacent stacks.

42.   An assessment of new fuze designs should be made to determine their vulnerability to blast and fragment impact compared to those used in the tests reported.

43.   That consideration be given to the potential for the use of barriers constructed of alternative materials between stacks of bombs. US work in the field should be reviewed and augmented where necessary by a UK programme of tests.

44.   That approved buffered storage configurations are published.

REFERENCES

1.   Letter DDSM (Wpns)4(RAF)/84/1/1 dated 15 Oct 93

2.   HQ Logistics Command Letter LC/504609/2/5 dated 1 August 1994

3.   Tests With Bombs, 150#, G P T-I, Army-Navy Explosives Safety Board Report dated 18 June 1945.

4.   ESTC Saltau Trials Report dated August 1947

5.   ESTC Dune and Heligoland Trials Report dated 1947

6.   Inter-Magazine Distances for Barricaded Open Bomb Stacks High Explosive Storage Test - BIG PAPA, Report AFWL-TR-67-132, May 1968

7.   Suppression of Propagation Between Stacks of Bombs, Kenneth R Shopher and Edward M Jacobs, Explosives Safety Branch, Air Force Inspection and Safety Center, Norton AFB, California, 22nd DoD Explosives Safety Seminar, Annaheim, CA, August 1986.

8.   Fragmentation Characteristics of Horizontally Stacked Bombs, Frank McCleskey, Booz Allen and Hamilton, 25th DoD Explosives Safety Seminar, Anaheim, CA, August 1992.

9.   Explosion Effects and Properties - Part III. Properties of Explosives and Explosive Compositions, Thomas N Hall & James R Holden, NSWC, Dahlgren, Report NSWC MP 88-116, October 1988.

10.   AASTP-1, Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives

TABLE 1 SUMMARY OF THE 1945 WINGATE TRIALS (Reference 3)

DONOR				BARRIER		ACCEPTOR				DONOR/ ACCEPTO RORIEN- TATION	RESULT
TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg	TYPE	CHARGE SEPARA- TION m	TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg		
150 LB	37.8	TNT	11338	NONE	15.24	150 LB	37.8	TNT	11338	N→T	NO REACTION MINOR DAMAGE
150 LB	37.8	TNT	11338	NONE	22.86	150 LB	37.8	TNT	11338	T→N	NO REACTION MINOR DAMAGE
150 LB	37.8	TNT	11338	NONE	7.62	150 LB	37.8	TNT	11338	N→T	NO REACTION MINOR DAMAGE
150 LB	37.8	TNT	11338	NONE	15.24	150 LB	37.8	TNT	11338	T→N	SOME REACTIONS MUCH DAMAGE
150 LB	37.8	TNT	11338	NONE	15.24	150 LB	37.8	TNT	11338	T→T	SOME REACTIONS MUCH DAMAGE
150 LB	37.8	TNT	11338	NONE	15.24	150 LB	37.8	TNT	11338	N→N	NO REACTION NO DAMAGE
150 LB	37.8	TNT	11338	NONE	22.86	150 LB	37.8	TNT	11338	T→T	SOME REACTIONS SOME DAMAGE
150 LB	37.8	TNT	11338	NONE	22.86	150 LB	37.8	TNT	11338	N→N	NO REACTION NO DAMAGE

TABLE 1 Continued

DONOR				BARRIER		ACCEPTOR				DONOR/ ACCEPTO RORIEN- TATION	RESULT
TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg	TYPE	CHARGE SEPARA- TION m	TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg		
150 LB	37.8	TNT	11338	NONE	30.48	150 LB	37.8	TNT	11338	T→T	NO REACTION SOME DAMAGE
150 LB	37.8	TNT	11338	NONE	30.48	150 LB	37.8	TNT	11338	N→N	NO REACTION MINOR DAMAGE
150 LB	37.8	TNT	11338	NONE	30.48	150 LB	37.8	TNT	11338	T→T	NO REACTION NO DAMAGE
150 LB	37.8	TNT	11338	NONE	30.48	150 LB	37.8	TNT	11338	N→N	NO REACTION MINOR DAMAGE
150 LB	37.8	TNT	22676	NONE	30.48	150 LB	37.8	TNT	22676	N→T	NO REACTION NO DAMAGE
150 LB	37.8	TNT	22676	NONE	38.1	150 LB	37.8	TNT	22676	T→N	NO REACTION NO DAMAGE
150 LB	37.8	TNT	22676	NONE	30.48	150 LB	37.8	TNT	22676	N→T	NO REACTION NO DAMAGE
150 LB	37.8	TNT	22676	NONE	30.48	150 LB	37.8	TNT	22676	T→N	NO REACTION MINOR DAMAGE

TABLE 1 Continued

DONOR				BARRIER		ACCEPTOR				DONOR/ ACCEPTO RORIEN- TATION	RESULT
TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg	TYPE	CHARGE SEPARA- TION m	TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg		
150 LB	37.8	TNT	11338	NONE	15.24	150 LB	37.8	TNT	11338	N→N	NO REACTION MINOR DAMAGE
150 LB	37.8	TNT	11338	NONE	15.24	150 LB	37.8	TNT	11338	N→N	NO REACTION MINOR DAMAGE

NOTES

i.   All tests were in single tier carpets.
ii.   Four rows oriented one way and five the other so that exposed faces of stack were noses and all tails pointed to the centre of the stack.

TABLE 2 SUMMARY OF THE 1946 ESTC SOLTAU TRIALS (Reference 4)

DONOR				BARRIER		ACCEPTOR				ORIEN-TATION	RESULT
TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg	TYPE	CHARGE SEPARA-TION m	TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg		
500 LB	88	MINOL	20333 (i)	TOP SOIL	9.50	500 LB	88	MINOL	20333	T→T	NO REACTION NO DAMAGE
250 lb	36.3	AMATOL 60/40	20390 (ii)	TOP SOIL	10.97	250 LB	36.3	PENTOLITE	20390	T→T	NO REACTION NO DAMAGE
250 LB	36.3	AMATOL 60/40 & PENTOLITE D1	36281 (iii)	TOP SOIL	10.97	250 LB	36.3	PENTOLITE D1	36281	T→T	NO REACTION NO DAMAGE
250 LB	36.3	AMATOL 60/40 & PENTOLITE D1	20390 (iv)	NONE	18.29	250 LB	36.3	AMATOL 60/40 & PENTOLITE D1	20391	T→T	BOTH STACKS DETONATED
250 LB	36.3	AMATOL 60/40 & PENTOLITE D1	20245 (v)	EMPTY BOMB CASES	18.29	250 LB	36.3	AMATOL 60/40 & PENTOLITE D1	20245	T→T	BOTH STACKS DETONATED
500 LB	88	MINOL 2 OR TNT OR RDX/TNT	36249 (vi)	TOP SOIL	10.97	4000 LB	1306.1	AMATOL	33959	T→T	NO REACTION NO DAMAGE

NOTES

i.   Donor and acceptor charges 5 rows of 40 bombs with 31 bombs on 2nd tier in front row.
ii.   Donor and acceptor charges 6 rows of 94 bombs in 3 tiers.
iii.   Donor and acceptor charges 6 rows of 167 bombs in 4 tiers.
iv.   Donor and acceptor charges 2 rows of 268 and 294 bombs in 7 tiers.
v.   Donor and acceptor charges 3 rows of 186 bombs in 4 tiers.
vi.   Donor and acceptor charges 5 rows of 83 bombs in 3 tiers.
vii.   All bombs were complete with exploder but without detonators. Transit plugs were fitted in the nose fuse wells.

TABLE 3 SUMMARY OF THE 1947 ESTC DUNE AND HELIGOLAND TRIALS (Reference 5)

DONOR				BARRIER		ACCEPTOR				ORIEN-TATION	RESULT
TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg	TYPE	CHARGE SEPARATION m	TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg		
250 LB	40.59	MINOL 2	22649 (i)	NONE	114.3	250 LB	40.59	MINOL 2	22649	T→T	DELAYED REACTION (25 MINUTES) FULL DETON'N
250 LB	40.59	MINOL 2	22649 (ii)	NONE	228.6	250 LB	40.59	MINOL 2	29225 (iii)	T→T	DELAYED REACTION (17 MINUTES) FULL DETON'N
250 LB	40.59	MINOL 2	22649 (ii)	NONE	228.6	250 LB	40.59	MINOL 2	15099 (iv)	T→T	NO REACTION

NOTES

i.   Donor and acceptor charges 3 rows of 47 bombs in each of 4 tiers.
ii.   Donor charge 3 rows of 47 bombs in each of 4 tiers.
iii.   Acceptor charge one continuous row of 188 bombs in each of 4 tiers.
iv.   Acceptor charge two rows of 47 bombs in each of 4 tiers. The two rows were both at 228.6m and were separated by a 27.21m gap. Thus there were no bombs directly opposite the donor.

TABLE 4 SUMMARY OF THE 1967 PROJECT 3758 (BIG PAPA) TRIALS (Reference 6)

DONOR				BARRIER		ACCEPTOR				ORIEN TATION	RESULT
TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg	TYPE	CHARGE SEPARATION m	TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg		
M66A2 (191) M117 (62)	535 175	TRITONAL	113400 (v)	EARTH	21.3	M66A2 (191) M117 (62)	535 175	TRITONAL	113400 (vi)	N→T	NO REACTION NO DAMAGE
M66A2 (191) M117 (62)	535 175	TRITONAL	113400 (v)	EARTH	17.8	M66A2 (55) M117 (26)	535 175	TRITONAL	34020 (vi)	S→S	NO REACTION NO DAMAGE
M66A2 (191) M117 (62)	535 175	TRITONAL	113400 (v)	EARTH	21.3	M66A2 (55) M117 (26)	535 175	TRITONAL	34020 (vi)	T→N	ONE BOMB LOW ORDER (ii)
M66A2 (191) M117 (62)	535 175	TRITONAL	113400 (v)	EARTH	48.2	M66A2 (55) M117 (26)	535 175	TRITONAL	34020 (vi)	S→S	NO REACTION NO DAMAGE
M66A2 (191) M117 (62)	535 175	TRITONAL	113400 (v)	EARTH	53.0	M66A2 (55) M117 (26)	535 175	TRITONAL	34020 (vi)	S→S (vii)	ONE BOMB LOW ORDER (iii)
M66A2 (191) M117 (62)	535 175	TRITONAL	113400 (v)	EARTH	21.3	M66A2 (55) M117 (26)	535 175	TRITONAL	34020 (vi)	T→N	NO REACTION NO DAMAGE (iv)
M66A2 (191) M117 (62)	535 175	TRITONAL	113400 (v)	EARTH	15.2	M66A2 (55) M117 (26)	535 175	TRITONAL	34020 (vi)	S→S	NO REACTION NO DAMAGE

TABLE 4 Continued

DONOR				BARRIER		ACCEPTOR				ORIEN TATION	RESULT
TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg	TYPE	CHARGE SEPARATION m	TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg		
M66A2 (191) M117 (62)	535 175	TRITONAL	113400 (v)	EARTH	21.3	M66A2 (55) M117 (26)	535 175	TRITONAL	34020 (vi)	N→T	NO REACTION NO DAMAGE
M117 (80)	175	TRITONAL	14000 (viii)	EARTH	24.4	M66A2	535	TRITONAL	20865	N→T	NO REACTION NO DAMAGE
M117 (80)	175	TRITONAL	14000 (VIII)	EARTH	24.4	M66A2	535	TRITONAL	20865	S→S	NO REACTION NO DAMAGE

NOTES

i.   Bombs mounted on concrete pads except where noted.
ii.   M117 trapped between concrete pad sections and exploded low order.
iii.   No concrete pad, low order event in M117.
iv.   No concrete pad.
v.   Donor charge 4 rows of 64 bombs in 3 tiers of M66A2 and 1 tier of M117 high.
vi.   Acceptor charge 4 rows of 28 bombs in 2 tiers of M66A2 and 1 tier of M117.
vii.   Acceptor charge offset along diagonal of donor.

TABLE 5 SUMMARY OF THE 1985 BUFFERED MK82 BOMB TRIALS (Reference 7)

DONOR				BARRIER		ACCEPTOR				ORIEN TATION	RESULT
TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg	TYPE	CHARGE SEPARATION m	TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg		
MK82 500LB	81.63	H6	8816	NONE	.76	MK82 500LB	81.63	H6	980	N→T	FULL DETONATION
MK82 500LB	81.63	H6	8816	NONE	.76	MK82 500LB	81.63	H6	980	T→N	FULL DETONATION
MK82 500LB (ii)	81.63	H6	8816	1 ROW 20MM TP PALLETS	1.52 + AMMO	MK82 500LB FUSED	81.63	H6	980	N→T	NO REACTION
MK82 500LB (ii)	81.63	H6	8816	1 ROW CBU58	1.52 + UNITS	MK82 500LB FUSED	81.63	H6	980	T→N	ONE LOW ORDER
MK82 500LB	81.63	H6	8816	7 ROWS MK 15 FINS	1.52 + FINS	MK82 500LB	81.63	H6	2939	T→N	NO REACTION
MK82 500LB	81.63	H6	8816	2 ROWS 20MM TP PALLETS	1.52 + AMMO	MK82 500LB	81.63	H6	2939	N→T	FULL DETONATION
MK82 500LB	81.63	H6	8816	2 ROWS CBU58	1.52 + UNITS	MK82 500LB	81.63	H6	2939	T→N	FULL DETONATION
MK82 500LB	81.63	H6	8816	5 ROWS MK 15 FINS	1.52 + FINS	MK82 500LB	81.63	H6	2939	N→T	NO REACTION
MK82 500LB (iii)	81.63	H6	8816	2 ROWS CBU58	1.52 + UNITS	MK82 500LB (i)	81.63	H6	2939	T→N	FULL DETONATION
MK82 500LB (iii)	81.63	H6	8816	2 ROWS MK 15 FINS	1.52 + FINS	MK82 500LB	81.63	H6	2939	N→T	FULL DETONATION

TABLE 5 Continued

DONOR				BARRIER		ACCEPTOR				ORIEN TATION	RESULT
TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg	TYPE	CHARGE SEPARATION m	TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg		
MK82 500LB (ii)	81.63	H6	8816	2 ROWS MAU FINS PALLETIZ ED	1.52 + FINS	MK82 500LB	81.63	H6	1959	N→N	NO REACTION
MK82 500LB (ii)	81.63	H6	8816	3 ROWS 20MM TP PALLETS	1.52 + AMMO	MK82 500LB	81.63	H6	1959	N→N	NO REACTION
MK82 500LB (iv)	81.63	H6	8816	2 ROWS CBU58	1.52 + UNITS	MK82 500LB	81.63	H6	2939	N→N	NO REACTION
MK82 500LB (iv)	81.63	H6	8816	3 ROWS CBU58	1.52 + UNITS	MK82 500LB	81.63	H6	2939	N→N	NO REACTION

NOTES

i.   All donors and acceptors had plastic nose and tail plugs unless otherwise stated.
ii.   All acceptors fused with Type 904 and 905 fuses.
iii.   All acceptors fitted with 150mm plastic rods in fuse wells.
iv.   All donors and acceptors fitted with steel rods in fuse wells.
v.   All stacks were 2 tiers high.

TABLE 6 SUMMARY OF THE 1986 BUFFERED MK84 BOMB TRIALS (Reference 7)

DONOR				BARRIER		ACCEPTOR				ORIEN-TATION	RESULT
TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg	TYPE	CHARGE SEPARATION m	TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg		
MK84 2000LB	428.6	H6	10285	NONE	4.57	MK84 2000LB	428.6	H6	5143	N→N	NO REACTION SOME DAMAGE
MK84 2000LB	428.6	H6	10285	NONE	4.57	MK84 2000LB	428.6	H6	5143	N→N	NO REACTION SOME DAMAGE
MK84 2000LB	428.6	H6	10285	NONE	4.57	MK84 2000LB	428.6	H6	5143	T→N	FULL DETONATION
MK84 2000LB	428.6	H6	10285	NONE	4.57	MK84 2000LB	428.6	H6	5143	N→T	FULL DETONATION
MK84 2000LB	428.6	H6	10285	NONE	4.57	MK84 2000LB	428.6	H6	5143	N→N	NO REACTION SOME DAMAGE
MK84 2000LB	428.6	H6	10285	NONE	4.57	MK84 2000LB	428.6	H6	5143	N→N	NO REACTION SOME DAMAGE
MK84 2000LB	428.6	H6	10285	1 ROW 55GAL DRUMS	4.57 INC DRUMS	MK84 2000LB	428.6	H6	5143	T→N	1 LOW ORDER SEVERE DAMAGE
MK84 2000LB	428.6	H6	10285	1 ROW 55GAL DRUMS	4.57 INC DRUMS	MK84 2000LB	428.6	H6	5143	N→T	1 LOW ORDER SEVERE DAMAGE
MK84 2000LB	428.6	H6	10285	5 ROWS 55GAL DRUMS	4.57 INC DRUMS	MK84 2000LB	428.6	H6	5143	T→N	1 LOW ORDER SEVERE DAMAGE

TABLE 6 Continued

DONOR				BARRIER		ACCEPTOR				ORIEN-TATION	RESULT
TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg	TYPE	CHARGE SEPARATION m	TYPE	NEQ kg	EXPLOSIVE	TOTAL NEQ kg		
MK84 2000LB	428.6	H6	10285	5 ROWS 55GAL DRUMS	4.57 INC DRUMS	MK84 2000LB	428.6	H6	5143	N→T	1 LOW ORDER SEVERE DAMAGE

NOTES

i.   All donors and acceptors fitted with steel fuse plugs.
ii.   Stacks were 3 tiers high

TABLE 7 LARGE SCALE GAP TEST RESULTS FOR EXPLOSIVES USED IN BOMBS (REFERENCE 9)

EXPLOSIVE	DENSITY gcm^{-3}	GAP NO OF CARDS	SHOCK PRESSURE GPa
AMATOL 60/40	1.71	175	2.5
COMP B	1.70	201	2.0
H6	1.75	166	3.0
MINOL 2	1.73	147	3.8
PENTOLITE	1.67	272	1.0
TNT	1.61	133	4.4
TRITONAL 80/20	1.72	100	5.5

ANNEX A   CURRENT PRESCRIPTIONS FOR THE CARPET STORAGE OF IRON BOMBS

5.1 Traversed Stacks (Modules of Bombs etc.)

5.1.1 D1-distances up to 30,000 kg or D2-distances from 30,001 to 125,000 kg as shown in Annex A, Table 1 may be used between stacks of unpackaged bombs of HD 1.1 when the following special conditions are met:

a. The stacks are separated by effective earth traverses.

b. The bombs must be relatively strong so as to withstand intense air shock without being crushed.

c. There should be the minimum of flammable dunnage, etc., which could catch alight and lead to subsequent mass explosion of a stack.

d. When the D1-distances are used then the stacking height must not exceed 1 m.

In the event of an explosion of one stack, the distances prevent simultaneous detonation of bombs in adjacent stacks. Some of the bombs at the Exposed Site may be buried and not immediately accessible, and some may be slightly damaged. There may be occasional fires and delayed low order explosions, particularly if the bombs are stacked on concrete pads.

D1-distances: $0.35Q^{1/3}$

D2-distances: $0.44Q^{1/3}$