RISKS FROM HANDLING EXPLOSIVES IN PORTS

By G E WILLIAMSON

HM Chief Inspector of Explosives, Health and Safety Executive
Magdalen House, Stanley Precinct, Bootle Merseyside, L20 3QZ, United Kingdom

INTRODUCTION AND SUMMARY

1. An earlier seminar paper (1) described the licensing of ports around the British coastline to handle explosives as required by the Dangerous Substances in Harbour Areas Regulations 1987.

2. At the same time as that regulatory work, an independent study (2) was being made of the major hazard aspects of the transport of dangerous substances by road, rail and by sea. The Report covered the transport of explosives by road and rail but it was considered inappropriate to try and assess the risks from handling explosives in ports prior to the completion of the licensing programme.

3. The results of the major hazards study were summarised in a further seminar paper on the risks from the transport of explosives (3) which also looked forward to the study and report on the risks from explosives in ports. Mention was made of the way licensing had generally led to significant reductions in the amounts of explosives, including military explosives, which could be handled and the problems then created back up the logistical chain.

4. The report of the study on the risks from handling explosives in ports has now been published (4) and is summarised here. The methodologies for estimating individual and societal risks at particular ports are outlined and are compared with those used in other similar studies. A rapid analysis technique based on the dominant risks from loading/unloading at berths, also described, provided a measure of the overall national risk.

5. The study confirmed the value of licensing - risks were generally found to be well managed but tolerable rather than trivial, falling in the lower part of the range where risks should be further reduced if reasonably practicable. Effective management of safety (5) remains essential.

SCOPE

6. The remit of the study, completed for the Health and Safety Commission under its Advisory Committee on Dangerous Substances, was to obtain best estimate values for the risks of moving Class 1 explosives through ports and to identify possible risk reduction measures. The technical objectives were:

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1996**	2. REPORT TYPE	3. DATES COVERED **00-00-1996 to 00-00-1996**

4. TITLE AND SUBTITLE **Risks from Handling Explosives in Ports**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Health and Safety Executive,Magdalen House, Stanley Precinct,Bootle Merseyside, L20 3QZ, United Kingdom,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM000767. Proceedings of the Twenty-Seventh DoD Explosives Safety Seminar Held in Las Vegas, NV on 22-26 August 1996.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

a. to establish the types and quantities of explosives moved through ports and the populations at risk from such movements;

b. to establish what types of explosive accidents could occur in ports, what is the likelihood of those accidents and what would be their consequences;

c. to establish a methodology for the estimation of individual and societal risk from the explosives trade at individual ports and nationally;

d. to establish a framework for the assessment of possible risk reduction measures.

THE STUDY

7. Since there are 150 ports around Great Britain licensed to handle explosives, it was necessary to restrict the in-depth studies to a relatively few locations which taken together covered the range of different types of port concerned; including size and location, infrastructure and method of moving explosives between ship and short, types of explosives handled, licence limits and volume of that trade. A rapid risk assessment technique was developed on the basis of the initial studies and then applied to the remainder of the explosives ports.

8. In the event, five ports and one jetty were selected for the detailed study, each handling all types of Class 1 explosives:

Port A, a major container port on a wide estuary with a high volume of trade in excess of 1000 te NEQ pa, and with licence limits equivalent to 200 te HD 1.1 A major gateway for military explosives moved into and out of the port in containers by both road and rail. Container gantry cranes used throughout.

Port B, a small break-bulk port located on a narrow river 11 km from the open sea, with a low volume of trade of less than 100 te NEQ pa and a licence limit equivalent to 2 te HD 1.1. The port handled a wide range of military and commercial explosives using fork-lift trucks and mobile cranes.

Port C, a major RoRo port within a narrow estuary and having a medium volume of trade between 100 and 1000 te NEQ pa and a licence limit equivalent to 2 te HD 1.1. Both military and commercial explosives passed through the port on road vehicles.

Port D, a major break-bulk port on the open sea with a high volume of trade in excess of 1000 te NEQ pa and a licence limit equivalent to 110 te HD 1.1 Trade was limited at the time of the study to military explosives of HD 1.2 brought into the port as palletised cargoes by road and handled by fork-lift truck and dock-side crane; operations typically involving over 1000 te gross weight over several days.

Port E, a small RoRo port on the open sea with a single pier for loading and unloading small RoRo ferries. A low volume of less than 100 te NEQ pa, typically involving just one vehicle at a time, though licence limit equivalent to 10 te HD 1.1.

Port F, a licensed jetty used for break-bulk and lightering when necessary. In an isolated position on a wide estuary having licence limits equivalent to 400 te HD 1.1 and a volume of trade high at over 1000 te NEQ pa. Typically used to handle large consignments of palletised aircraft bombs delivered by container lorry, the jetty employed fork-lift trucks and mobile cranes. Bombs loaded onto lighters were transported over 16 km out to anchorages for transfer onto ocean-going ships.

Potential Causes of Explosives Events in Ports

9. The principal causes were considered to be the presence of unsafe items in explosives loads or the involvement of explosives in energetic accidents. Cargoes which contain unsafe explosives may initiate spontaneously or with relatively low energy inputs. A number of other, different types of accidents could occur in ports at one stage or another, such as during the transport of a cargo between the port entrance and berth, breaking bulk on the quay-side, short to ship transfers or during stowage of break-bulk cargoes on a ship, and which could in theory result in an initiation of an explosives cargo. That is if imparted stimuli such as impact/friction, heat, electrostatic or electromagnetic energies or by chemical reaction are sufficient.

10. Leaving unsafe explosives apart, these accidents were identified by a hazard and operability (HAZOP) study and those then recognised as too improbably to warrant further study set aside. In total, nine scenarios, involving fire or impact, were selected for further study:

Fire Accidents	- road vehicle fires - train fires - ship fires
Impact accidents	- road vehicle crashes and collisions - train derailments and collisions - crushing or penetration of packages by fork-lift trucks - falls of loads from cranes - ships striking vessels loading explosives - ship collisions

Categorisation of Explosives Cargoes

11. The likelihood that such scenarios would lead to an explosives event and the consequences which would then result will both depend on the nature of the cargo being handled. But it is not practicable to analyse separately the risks by each of the many different types and sizes of explosives cargoes. As in the earlier study of major hazards in transport (2), the solution was to categorise the cargoes into a small number of groups with respect to the important risk factors and so that all explosives belonging to a particular group may be considered either to

produce similar effects on initiating or to be, broadly speaking, equally susceptible to energetic stimuli.

12. After considering the important risks factors - the susceptibility of the cargo to accidental initiation by impact or by fire, the hazard that would be produced and the NEQ of the cargo - explosives were initially categorised into six hazard groups, three impact risk groups and two fire risk groups which when combined produced ten out of a possible thirty categories. It was seen as unlikely that correctly packaged explosives would be initiated if involved in the types of impact accidents that could be anticipated to occur in ports, though recognised that some (designated as 11) would be more susceptible than the vast majority of others (12) and that a few more (13) would be much less sensitive than the majority and unlikely to be initiated in any credible impact accident. Fire would generally pose a much greater threat, the distinction to be made then between those explosives that would most probably burn to explosion following ignition (F1) and those unlikely to behave in that way (F2). The categorisation scheme in summary:

Hazard Division 1.1	-Articles	11,F1...........	12,F1............	13,F1
	-Substances		12,F1.....12.F2	
Hazard Division 1.2	-Articles	11,F1...........	12,F1	
Hazard Division 1.3	-Articles	11,F1...........	12,F1	
	-Substances		12,F1	

13. Rules were made for the categorisation of cargoes containing different types of explosive; Hazard Division is the usual way as HD1.1>HD1.2>HD1.3, impact risk group then as 11>12>13 and fire risk group F1>F2 - in each case referring to the substance or article which comes highest in precedence.

14. To complete the categorisation process it is necessary to take account of the different sizes of load moved through ports in order later to estimate the consequences of any event. Again, it is not practicable to analyse all sizes of load and again it becomes necessary to group loads into a small number of notional sizes of cargo. The method adopted was to determine for each of the ten categories of cargo listed in para 12, the mean NEQ of loads within the bands: 1 - 99, 100 - 999, 1000 - 9999, 10,000 - 99,999, 100,000 - 1,000,000 Kg. Analysis of port traffic data then produced breakdowns of explosives cargoes by hazard division, impact risk group, fire risk group and size of load carried by road, rail and ship at each of the six Ports A to E. As an example, lorry cargoes made up of articles of HD 1.1 at Port C partitioned into three notional sizes:

Articles of HD 1.1/12/F1	4 kg	2% of total movements
	400kg	4%
	1800kg	6%

Likelihood of Events

15. Analysis of historical data gave rates for each of the dangerous occurrences listed above at para 10, and accident data, trials data and expert judgement were used to deduce the conditional probability that a specified category of explosives load would initiate in the event of its involvement in a particular kind of dangerous occurrence. Computing those rates and probabilities with traffic data for the annual numbers of movements of the different types and sizes of explosives cargoes moved through ports gave frequencies with which different types and sizes of explosives events might potentially occur in ports. For the HD 1.1 (A) loads at Port C, the frequencies v fire on heavy goods vehicles (HGVs) were estimated as:

cargo-damaging lorry fire rate for HGVs **(R)**	5.10^{-9} per vehicle km
conditional probability of initiation as F1 **(P)**	1
annual traffic levels for 4, 400 & 1800 kg **(T)**	1.86, 3.72 and 5.58 vehicle-km
frequencies of events for 4, 400 & 1800 kg	$9.10^{-9,}$ 2.10^{-8} and 3.10^{-8} (RPT) pa

16. In addition to the possibility of explosives events arising from fire and impact accidents, experience showed that these events could also occur spontaneously should unsafe items be present in explosive loads. In considering the likelihood of such accidents the approach was pragmatic; noting past failures and assuming a similar rate of further failures in the future. 50% of all initiating events that have occurred during transport operations since 1950 were caused by unsafe explosives items of one kind or another - items badly designed, manufactured or packaged or else mis-handled or allowed to deteriorate. An allowance for the risks of unsafe explosives was made by simply doubling the explosives event frequencies derived for fire and impact accidents.

17. The arguments which generated those values are well set out in the Report as is a discussion of the uncertainties involved. It was concluded that the small amount of accident and trials data which was available did suggest that most of the results were likely to err on the side of caution. But the point was also made that while the use of such values was in keeping with the "conservative best estimate approach" to risk analysis, further research to establish objective values of conditional probability and of the potential threat posed by unsafe explosives would clearly be desirable.

Consequence of Explosives Events

18. The focus as in the earlier study (2,3) was on the risk of explosives events causing fatalities not on other consequences such as injury, loss of assets or property damage. Several models, developed for the most part under the UK's MOD Explosives Storage and Transport Committee as improved versions of those available for the previous study, were used to determine the distances from an explosion at which lethal effects could occur. Those models covered blast effects, primary fragments and the effects of idealised or non-idealised fires to

persons either indoors or outdoors as appropriate for articles and substances of HDs 1.1 and 1.3. It was assumed t hat an accidental initiation of HD 1.2 load might cause up to four fatalities. Although the models were likely to produce some slight overestimates, care was taken to avoid double counting.

19. The hazard ranges associated with the various types and sizes of explosives loads moved through the ports were related to levels of lethality of 100% (eg L_{100}), 90%, 50%, 10% and 1%. Typical results for a cargo of 200kg of HD 1.1 substances on say a lorry were:

Hazard Range	***Distance to Persons Indoors (m)***	***Distance to Persons Outdoors (m)***
$\mathbf{L_{100}}$	**18.00**	**14.00**
$\mathbf{L_{90}}$	**19.00**	**14.50**
$\mathbf{L_{50}}$	**22.00**	**15.00**
$\mathbf{L_{10}}$	**32.00**	**17.00**
$\mathbf{L_{01}}$	**56.00**	**19.00**

20. Those hazard ranges were then applied to the population data provided by each of the ports. Account was taken of the fact that at some ports the numbers of persons who would be encompassed by the hazard ranges could vary with both time of day and day of week, and allowance was also made when it seemed likely that people would be able to escape from the scene of an accident before the explosives event occurred. An average fatality probability of 0.95 was assumed for those persons within the zone bounded by L_{100} and L_{90} ranges and 0.7, 0.3 and 0.05 for the other zones out to the L_{01} range. As before, the various uncertainties and shades of caution were well recognised; work continues in the UK to further develop and refine the different explosion effects models.

21. The frequency and fatality results obtained for the various points around each port at which an explosives event could be initiated were combined to provide two measures of societal risk: FN curves which show the estimated frequency (F) of events resulting in N or more fatalities: and "expectation values" which express the long term average number of fatalities per year that could be expected from the explosives trade at each of the ports. At Port C for example, there were twelve representative types and sizes of loads for which frequency and fatality estimates had to be determined for explosive events on ships docked there and from which FN data could be constructed:

Frequency (F) of N or more fatalities (per year)					
N>=1	**N>=5**	**N>=10**	**N>=15**	**N>=20**	**N>=50**
$4.3.10^{-5}$	**$2.6.10^{-5}$**	**$2.0.10^{-5}$**	**$2.0.10^{-5}$**	**$1.2.10^{-5}$**	**4.10^{-6}**

The expectation values were calculated as the produce of each of the twelve pairs of frequency and fatality estimates, the sum of the values - ie 1.10^{-3} fatalities per year - then giving the overall expectation value for explosives events on ships docked at Port C.

22. Similar calculations were made for all other points in Port C where explosives events could potentially occur, and in the same way for all the ports concerned. Most of the risk of moving explosives through ports appears to be concentrated at berths and other points of loading and unloading; in part a function of the licensing system which seeks to give high levels of protection to those not directly involved in the explosives handling operations. Individual Risks at berths were generally of the order of 10^{-5} per year, the percentages of total expectation value derived for berths lay in the range 52 to 100% and generally dominated values obtained for other locations.

Rapid Risk Analysis

23. The rapid risk assessment technique stands on the result that most of the risk involved in moving explosives through ports is concentrated on the berths where explosives are loaded onto and off-loaded from ships. It takes account of the hazard group and quantities of explosives handled, the number of cargoes handled in a representative period and type of handling operation, and the numbers of persons at or around the berth and their distances from the explosives cargo.

24. Data for those parameters should be obtained by questionnaire and translated into frequency and fatality estimates, then used to construct FN plots. Fatal explosives events are estimated to occur in ports nationally with a frequency of 6.10^{-4} yr^{-1} The potential for more than ten fatalities appeared to be limited to the minority of ports where relatively large numbers of people may be present on explosives ships or are employed at explosives berths, or otherwise at ports where passenger vessels may vet involved. Events resulting in around 15 to 20 fatalities were estimated to occur nationally with a frequency of 1.10^{-4}, and for 100 or more at 7.10^{-9} yr^{-1}.

Conclusions

25. It was outside the remit for the study to make decisions about the tolerability of the estimated risks though they appear tolerable when compared with the criteria developed in the earlier study on major hazards in transport (2,3), if subject to risk reduction measures as may be reasonably practicable. The risks were described rather as well managed providing that existing standards of management were maintained or further enhanced. Another signpost for improvement related to the preparation and effective implementation of the emergency plan

required by legislation, the way that may assist the evacuation of personnel before an incident involving explosives which takes time to escalate into an explosives event can do that.

26. The study, just a snapshot in time, did not seek to compare the risks from different modes of handling explosives in ports. However, methods which keep the number of people exposed to a minimum must be preferable.

REFERENCES

1. Williamson G E. The licensing of ports and harbours handling explosives. Proceedings of 23rd DoD Explosives Safety Seminar, Atlanta, 1988.

2. Health and Safety Commission - Advisory Committee on Dangerous Substances. Major hazard aspects of the transport of dangerous substances: Report and Appendices. London HMSO 1991. ISBN 011 885676 6.

3. Williamson G E . Risks from the transport of explosives. Proceedings of 25th DoD Explosives Safety Seminar, Anaheim, 1992.

4. Health and Safety Commission - Advisory Committee on Dangerous Substances. Risks from handling explosives in ports. HSE Books 1995. ISBN 0-7176-0917-0.

5. Williamson G E. Safety management in the explosives industry. Proceedings of 24th DoD Explosives Safety Seminar, St Louis, 1990.