WASC 2028

Remote Manufacturing
—
Facility Requirements

HSE
Health & Safety Executive

CBI

EXPLOSIVES INDUSTRY GROUP

REQUIREMENTS FOR REMOTE EXPLOSIVES MANUFACTURING FACILITIES

January 2005

CONTENTS

SECTION 1 FOREWORD

1.1 This guidance has been produced by a joint working party of the Health and Safety Executive and the Explosives Industry Group of the Confederation of British Industry. The document contents builds upon earlier work carried out on this topic.[1] It is now provided as a guide for determining which explosives manufacturing operations are conducted remotely or non-remotely, and the corresponding safeguards for each.

1.2 This guidance represents good practice found within the Explosives Industry. Following it is not compulsory and persons are free to take other action. However, by following the guidance, persons would normally be doing enough to comply with their legal duties. HSE and the CBI Explosives Industry Group may refer to this guidance as illustrating good practice.

1.3 A list of current legislation and information is included at Appendix 1 to this document.

1.4 Whilst every effort has been made to cover appropriate legislation and good practice at the time of publication of this guidance, neither the CBI nor its servants or agents can accept responsibility for, or liabilities incurred directly or indirectly as a result of, any errors or omissions within this document. Those persons involved in the Explosives Industry are responsible for taking their own legal and other advice as they see fit. Readers are strongly advised to check for any changes in legislation since the publication of this guidance.

1.5 Nor do the CBI, its servants and agents make any representation expressed or implied that the products and product ranges or the processes, equipment or materials referred to in this guidance are suitable, satisfactory or appropriate for the purpose or purported purposes set out or referred to in this guidance and the CBI, its servants and agents accept no responsibility or liability therefor.

1.6 It is not the intention of this guidance to be used as a technical manual by those inexperienced in explosives manufacture, to enable them to carry out such activities. Those not experienced in the field should seek expert assistance.

SECTION 2 INTRODUCTION

2.1 Certain explosive operations carry such a high risk of accidental explosion that they need to be conducted remotely. This can be achieved by locating operators in a 'remote' (but located nearby) control room or process area, protected from the hazardous operation by robust structures, engineering safeguards and spacing. The structure containing the hazardous operation is sometimes termed 'the donor' and that containing the operators 'the receptor'.

2.2 Remote manufacturing operations can be defined as those possessing effective segregation of people from the operation, whether by engineering safeguards, separation distance, or both. This is to assure the protection of process operatives and other people who might thereby be exposed to the consequences of an explosion/fire event. Effective physical protection could involve the use of cell structures, control rooms, or reinforced concrete barricades for large-scale operations. Captured key systems such as those manufactured by Castell and Fortress may be considered as effective engineering controls to exclude personnel from enclosures containing high risk explosives processing operations.

2.3 Where the risk of an accidental explosion is low and complete physical protection of the operator is unnecessary, then operations may be conducted in non-remote facilities. Non-remote manufacturing operations can be defined as those where effective physical separation is not required, but where suitable protection is provided by a safe system of work. These types of operation should generally only involve the use of small quantities of sensitive explosives behind suitable protective screening and with suitable personal protective equipment, or the use of relatively insensitive explosive materials.

2.4 The purpose of this document is to consider the following:

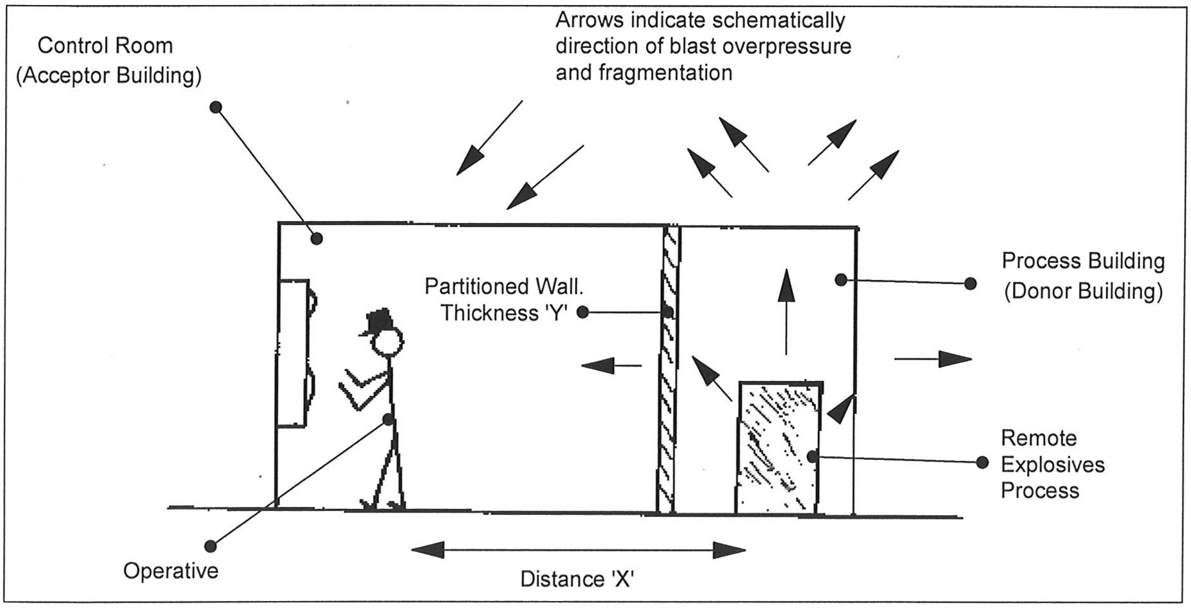
(i) The basis for conducting explosives manufacturing operations remotely or non-remotely.

(ii) The provision of appropriate safeguards for fire and explosion hazards. Smoke, fume and toxic hazards are not covered by this guidance.

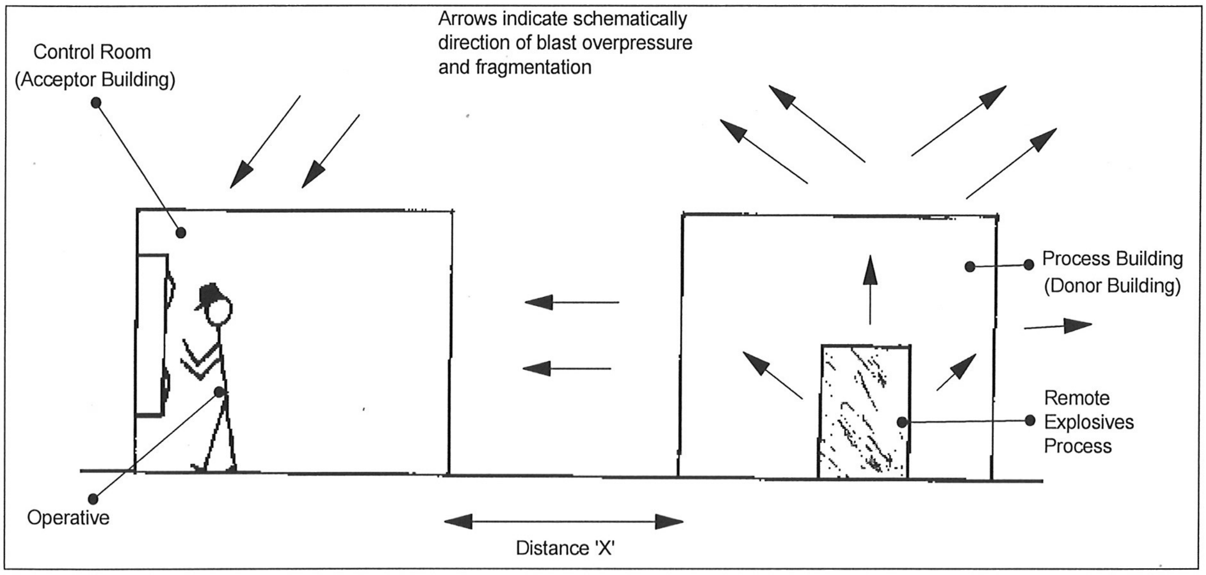
(iii) The safety of persons located in the control room or process area either within the manufacturing facility, or located within the process building distance of the facility – see scenarios depicted in Figure 1. *[Figure 1 shows illustrations of a remote operation where the control room is adjacent to a hazardous process (scenario 1), separated by distance (scenario 2), or in an adjacent process building within the process building distance of the hazardous process (scenario 3)].*

2.5 This guidance does not set out to provide detailed technical advice on how to carry out particular activities, but rather to provide an overview and highlight issues that need to be considered when planning and undertaking such activities. The reader is also directed further to other relevant sources of information.

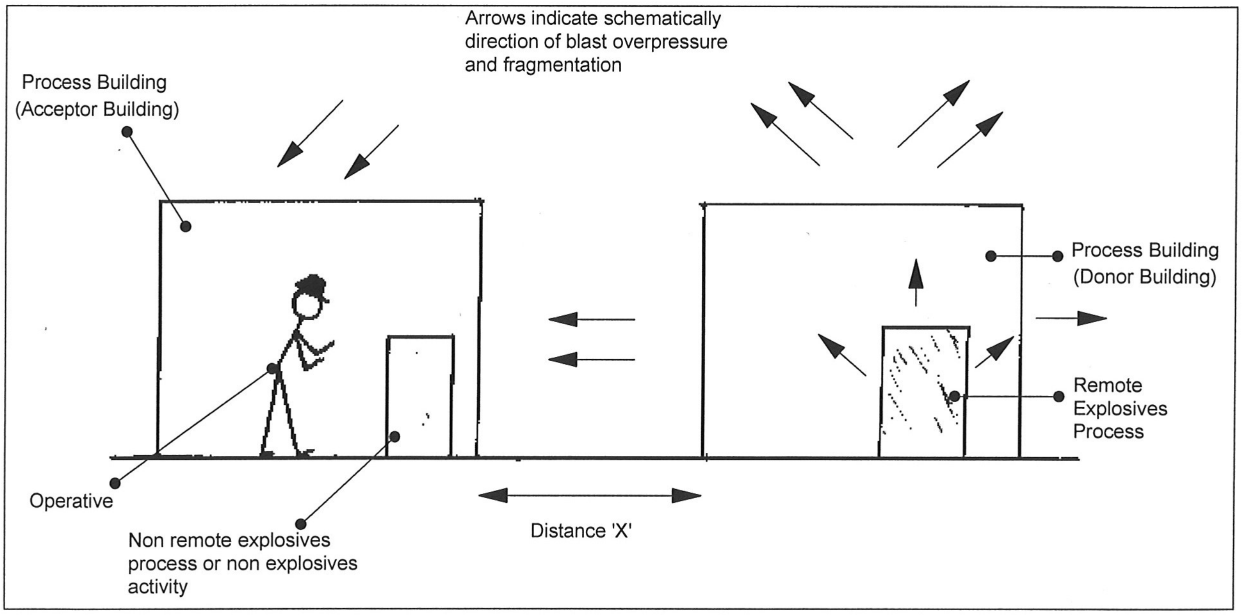
Figure 1: Schematic illustrations of various scenarios where a control room, or a non-explosives building is occupied, in relation to a remote explosives manufacturing process.



Scenario 1: Occupant located in a control room associated with a remote explosives process operation.



Scenario 2: Occupant located in a nearby control room associated with a remote explosives process operation.



Scenario 3: Occupant located in a process building adjacent to where a remote explosives operation is taking place.

Note: Process building distances are a compromise between the level of safety given to personnel and the degree of convenience they give by having process buildings relatively close together.

SECTION 3 BACKGROUND

3.1 The Manufacture and Storage of Explosives Regulations (MSER) requires, amongst other things, that persons should be protected from the effects of fire or explosion. Other legislation such as the Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) requires duty holders to conduct specific risk assessments. For example: such risk assessments would include remote manufacturing facilities and the potential effects on people located in the vicinity.

3.2 The design and construction of such remote manufacturing facilities should be in accordance with the Construction (Design and Management) Regulations (CDM) 1994, to ensure that facility designers are competent and capable of designing out foreseeable risks and also incorporating mitigation features at the start of a new build or building modification project. Due consideration must also be taken of the safety and integrity of equipment used for either remote mixing, machining or pressing operations, along with physical safeguarding barriers. Equipment purchase should comply with the essential health and safety requirements of the Supply of Machinery (Safety) Regulations 1992 (SMSR), and remain safe whilst being used, cleaned and maintained under the requirements of the Provision and Use of Work Equipment Regulations 1998 (PUWER).

3.3 Over recent years there have been a number of serious UK incidents associated with remote explosives manufacturing operations:

(i) One incident involved the remote processing of propellant which, when accidentally initiated, produced much more violent effects than expected and caused serious injuries to the operators in the remote control room. This was due to the progressive development and use of materials that were much more energetic than originally conceived.

(ii) A second incident was associated with the remote incremental pressing of a firework that, when it initiated, propelled one half of the heavy metal press die through the protective barrier between the press and the operator, who was killed.

(iii) A third explosion involved unauthorised working inside a remote manufacturing exclusion zone, which resulted in multiple fatalities.

SECTION 4 SELECTION OF THE MANUFACTURING PROCESS

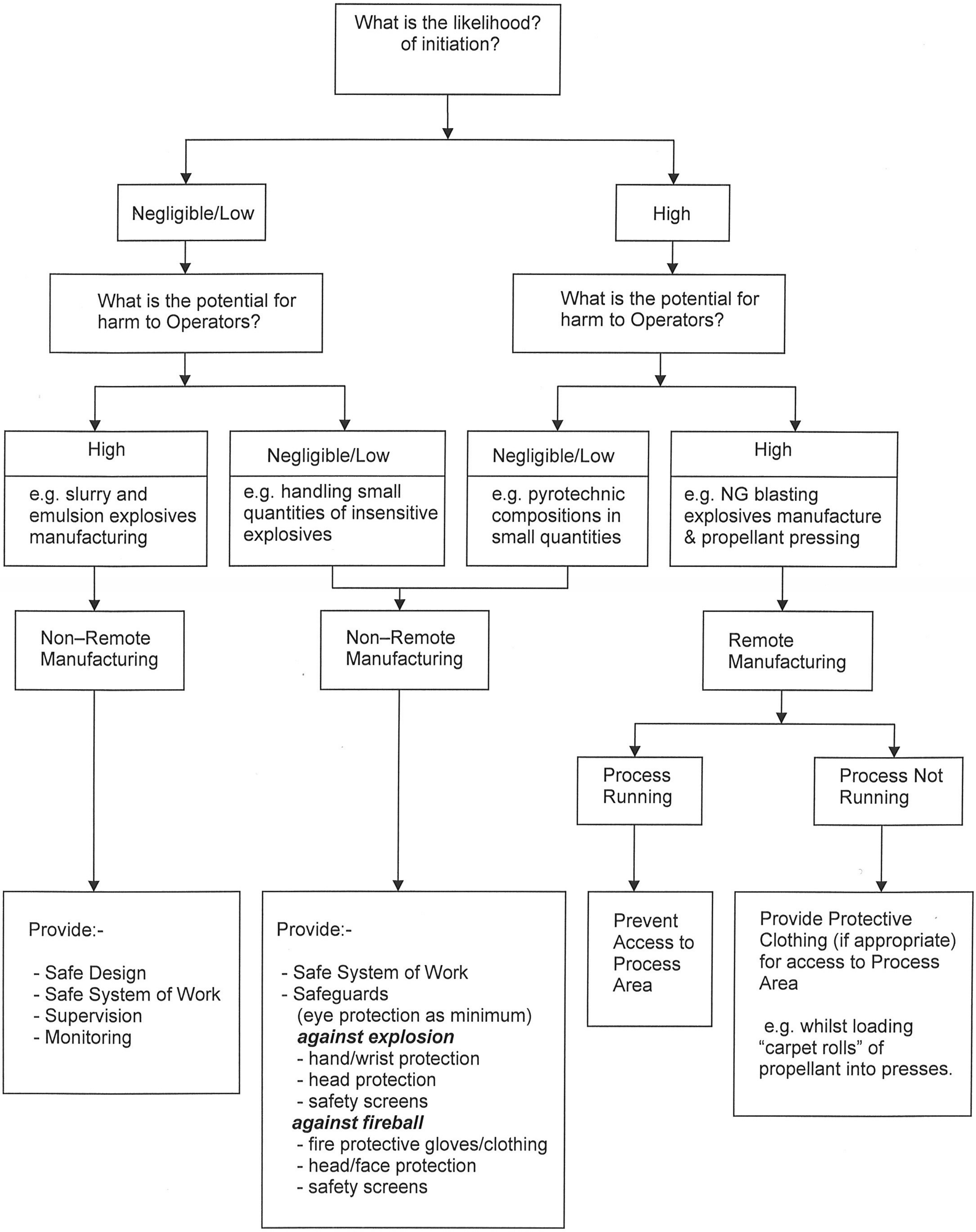
4.1 Generally the safest, but by far the most expensive option for any explosives manufacturer, would be to perform all explosives manufacturing processes remotely. For many operations clearly such arrangements could well be outside the terms of 'reasonable practicability', with less expensive options involving non-remote "hands-on" manufacturing supported by a range of safeguards.

4.2 To identify processes that should be conducted remotely requires an initial assessment both of the potential hazards and likelihood of initiations associated with all stages of the explosives manufacturing operations. Such assessments should have due regard to:

- The quantity of material present
- The nature of the plant (confinement in particular)
- The conditions of manufacturing (heat and mechanical input); and
- The foreseeable process deviations (operator errors, impurities, malfunctions).

A selection model is set down in Figure 2 to guide readers on reaching a decision as to the most appropriate explosives manufacturing method.

Figure 2: Selection model for Remote versus Non-Remote Manufacturing Requirements and Fire/Explosion Safeguards.



SECTION 5 HAZARDS FROM EXPLOSIVES

5.1 In recent years, UK licences for explosives factories and magazines have referred to HTs and not the UN HDs where the classification is assigned to explosives which are packaged for transport according to the UN Recommendations. The nature of packaging (or lack of it), the quantity and arrangement in storage can have a significant affect on the hazard presented in non-transport situations. HTs have been defined in the terms of the licence by descriptions similar to those for the UN HDs employed in the classification of explosives (see Table below).

Hazard Type 1	An explosive which has a mass explosion hazard *(a mass explosion is one in which the entire body of explosives explodes as one);*
Hazard Type 2	An explosive which has a serious projectile hazard but does not have a mass explosion hazard;
Hazard Type 3	An explosive which has a fire hazard and either a minor blast hazard or a minor projection hazard, or both, but does not have a mass explosion hazard (i.e. *those explosives which give rise to considerable radiant heat or which burn to produce a minor blast or projection hazard);* and
Hazard Type 4	An explosive which has a fire or slight explosion hazard, or both, with only local effect (i.e. *those explosives which present only a low hazard in the event of ignition or initiation, where no significant blast or projection of fragments of appreciable size or range is expected).*

5.2 The Hazard Type system applies to the hazards presented by explosives throughout the course of their manufacture, storage and handling, and may require tests and trials to be undertaken to determine how an explosive behaves as conditions change. Both the explosives licence and the process safeguards should properly capture the hazards presented by the explosives materials in various stages of manufacture and subsequent handling. For example: propellant powder for shotgun cartridge manufacturing arrives in a package with a HT3 designation. During subsequent handling on the plant, it presents a HT1 hazard in the bulk storage hopper. Thereafter in the finished product, the packaged cartridges are HT4. Confinement is one of the main drivers for directing the hazard of energetic materials. Another example is detonators. These articles mainly classified as UN HD 1.4 for transport, but can present a HT1 hazard when stored together outside of their packaging.

5.3 Other hazard-controlling factors include the processing temperature, and whether or not the configuration is greater than the critical charge diameter (the diameter which is just large enough to support a propagating detonation). Examples of where a combination of these factors may occur are within (a) an extrusion process (where the main considerations are critical diameter, confinement, pressure and, with certain pressing operations, elevated temperature); and (b) a hopper in a cartridge filling operation (where the critical considerations are propellant depth and confinement). Additional information and discussion of the hazards associated with explosives is given at Appendix 2.

SECTION 6 LIKELIHOOD OF INITIATION

6.1 The likelihood of accidental initiation during the manufacture of explosives involves a balance between the energy imparted to the explosive and its sensitiveness. A precise assessment of this may not be possible, but some indication of the likely behaviour under the proposed conditions of manufacture may be available from recorded experiences elsewhere, or be anticipated from the chemical structure of the substances. Further information can be obtained by measuring how sensitive the substance is to external stimuli such as impact, friction and heat using standard explosives testing techniques and criteria.[2] In addition, it is necessary to establish the thermal stability of the materials at the proposed processing temperatures. Much information has been published on these matters.[3-14] It should be noted, however, that properties such as sensitiveness could be greatly increased when a substance is subsequently contaminated with gritty or catalytic materials or when the substance is heated. Ideally, substances and mixtures should be tested under the actual conditions experienced in manufacturing; this should include consideration of any intermediates that may be formed.

SECTION 7 REMOTE HANDLING PROCESSES

7.1 For explosives manufacturing operations, where on initiation there exists the potential to kill or seriously injure people and where the likelihood of initiation is significant, the basic premise must be that such operations should be carried out remotely. Before considering a movement away from a remote manufacturing arrangement to a hands-on situation, it will be necessary to study carefully the proposal against fundamental hazards/sensitiveness information on the raw materials, intermediates and finished products; this might also require a series of tests and trials. If any doubt exists about either the potential hazards of explosives initiation or the likelihood, then a remote manufacturing operation should be conducted.

7.2 Examples of explosives operations that are performed remotely are:

i) incorporation of pyrotechnic compositions.

ii) mixing/incorporation of NG-based propellants and blasting explosives.

iii) detonator manufacturing lines.

iv) propellant extrusion/pressing.

v) machining of explosives

vi) pressing of MTV flare compositions.

A table of examples of remotely operated explosives/activities along with their associated incident history, and typical non-remote hands-on processes, is given in Appendix 3.

SECTION 8 NON REMOTE HANDLING PROCESSES

8.1 Processes not requiring remote handling precautions are those where the consequences of initiating the materials are slight or are fully contained (e.g. handling of devices such as actuators), or where the likelihood of initiation is very small or negligible (e.g. manufacture of slurry explosives). For the latter situation, where certainly the final product is considered to be insensitive, it is important that not only must the effect of the potential stimuli on the end product and on intermediates be evaluated for the normal course of manufacturing, but also for foreseeable process malfunctions; for example resulting from operator error in the order of materials addition in a mixing process. In following up this evaluation, areas of weakness in the chosen safety regime may well be found, and then steps must be taken to eliminate them. The guide words used in the formal Hazard and Operability approach are useful in this context.[15-17]

SECTION 9 REMOTE HANDLING PRECAUTIONS

9.1 General Principle of Personnel Protection

9.1.1 In those circumstances where an explosives operation presents a sufficiently high likelihood of a fire/explosion hazard being realised, such that it should be performed remotely, the facility operating bay or the control room should be appropriately designed and constructed in a manner to safeguard personnel from serious injury.

9.2 Containment of Fire/Explosion Effects

9.2.1 The primary requirement of a remote manufacturing facility is to provide personnel in the vicinity with a predetermined level of protection against the effects of accidental initiation of the materials in process. For relatively small quantities of explosives (few kilograms) it is possible to completely contain the effects of a fire/explosion. For larger quantities of explosives this is not practicable, and only near-fully contained structures are used. These are designed to release decomposition products/blast pressures to atmosphere in a predetermined direction to areas where personnel, equipment, etc are protected primarily by distance. The design of containment structures is covered extensively in specific literature.[18]

9.3 Hazard Reduction

9.3.1 Hazard reduction can be achieved by a number of measures. Firstly, the quantity of materials in processing should be kept to a minimum. To this end, continuous rather than batch manufacturing presents a lower inventory and is preferred. Secondly, to ensure that the initiation of one quantity of material does not communicate with other quantities of explosives, which might be in adjacent production facilities, it is usual to prevent these "domino" effects by using fire/blast/fragment resistant barricades. Where the production unit is housed in a purpose designed structure that vents combustion and explosion effects through a soft wall or roof, care should be taken to direct these effects to a safe place. To protect persons who might be affected by these effects, the necessary protection is usually given by a combination of distance and barricades.[19]

9.4 Levels of Protection

9.4.1 Persons located at a control panel inside a control room, or within the process building distance should not be exposed to the following:

(a) A blast overpressure in excess of the threshold for eardrum rupture.
(b) Structural collapse (blast or debris induced).
(c) Missiles or fragments sufficient to cause significant injuries.
(d) Thermal radiation sufficient to cause more than reddening of the skin.

9.5 Exclusion from Remotely Controlled Manufacturing Areas

9.5.1 It is essential to prevent access to the remote manufacturing area during the critical manufacturing period. Wherever possible, physical barriers must be used to prevent such access. Safeguards must also be taken to prevent the approach and possible access to the manufacturing area by persons not associated with the particular plant. Where not possible, other effective means should be used.

9.5.2. Depending on the operation, it may be important to observe the area by using mirrors, or closed-circuit television cameras, infra-red detectors, video recording equipment, audio monitoring devices, or a combination of any of these. This will facilitate corrective or emergency stop action to be taken in the event of an unusual occurrence. Emergency stop action might include both the initiation of fire alarms and operation of drencher systems. The electrical monitoring devices should be connected in such a way that processing work cannot commence in the area without the devices being in operation.

9.5.3 Remote control systems should be arranged in a manner to allow setting up and calibration to be done in proximity to the explosives, without permitting the full range of events to take place whilst the operator is in the remote processing area.

9.5.4 When using machines, appropriate start-up and shut-down procedures should be used. For example, with a remote CNC lathe, the procedure should be such that on a controlled shutdown, the machine should not stop with the tool in direct contact with the piece of explosives work.

9.5.5 Where robots or other potentially hazardous machinery are used, such operations may also need to be performed remotely or the area "fenced off" to prevent access. Specific guidance on both these matters is available.[20-23]

9.5.6 An effective method for securing entrances to fenced-off manufacturing areas, is the "captive key" (e.g. Castell Key) type of interlock system. These should be arranged to either isolate positively the power supply or control to the manufacturing unit if any of the entrances are open. There are a number of ways this can be done, but the essential elements are locks on all access gates to the danger area, together with another lock on the on-off switch to the manufacturing unit. Thus, the latter cannot be switched on without the key in place and that key cannot be released from the captive key system until all the gates are closed. A key exchange interlock system on an access door to a manufacturing area is given at Figure 3.

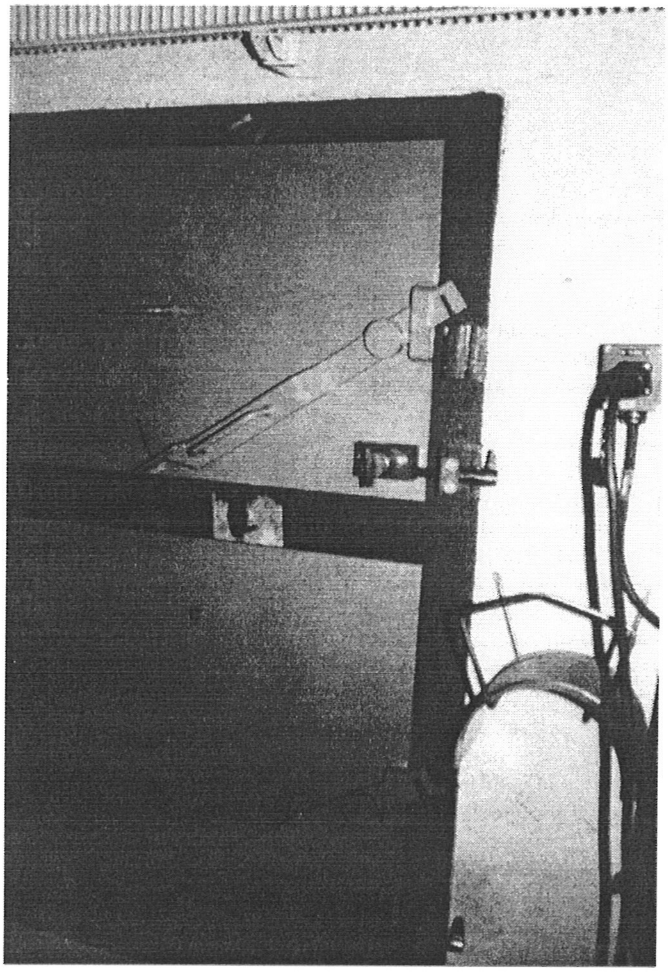


Figure 3: A key exchange interlock system on the access door to a manufacturing area.

SECTION 10 NON-REMOTE HANDLING PRECAUTIONS

10.1 For non-remote handling processes where the consequences of initiating the materials is thought to be slight, but the likelihood significant, care needs to be exercised to protect the operator handling the potential explosion effects from the substance or article. Protection of hands and eyes is particularly important. The extent of necessary precautions will need to be judged, but often this can be helped by deliberately and safely initiating the substance or article and observing the potential for harm, perhaps using manikins as 'targets'.

10.2 It is recognised that certain particularly intricate operations can only be done by hand. Careful consideration should be given to the acceptability of such operations in terms of quantity of explosive involved, sensitiveness and necessary precautions. Wherever practicable, "safer" substitutes should be used.

10.3 It is essential that any safety regime that relies on very small quantities of explosives as a safety feature, also incorporates controls that eliminate any risk of communication between individual items and minimises the quantities of hazardous materials present in the workroom. Associated with this requirement may be a system of work that requires finished articles to be removed from the workroom on a regular basis, say just before the start of every break. In addition it may also be necessary to hold "in-transit" explosives in the workroom inside containers, which are designed to withstand the effects of an adjacent explosives initiation. The design of such "operational" containers/shields is described in specific literature.[24]

SECTION 11 DESIGN AND CONSTRUCTION OF BUILDINGS CRITERIA

11.1 Design of Process Buildings

11.1.1 People are generally protected from any accidental fire or explosion by sufficient separation distance, a shelter structure for people, a containment structure for the explosives operation, or a combination of these.

11.1.2 Shelters should be designed to resist and attenuate blast sufficiently and resist primary and secondary fragments, including spalling from walls inside the shelter. It may be necessary for the entrances to be sealed by blast doors. Openings required for process operations, such as ventilation, equipment access etc, may be sealed by blast valves or shields. The roof of the shelter may need to be de-coupled from the roof of the process cell.

11.1.3 An alternative means of protecting people is to use full or partial containment structures around the explosives or by the use of barriers.

11.1.4 The design of process buildings should ensure that any fire and explosion in one location is not propagated to other cells or compartments in the building. The number of people involved should also be minimised consistent with the safety and security of operations.

11.1.5 In practice, explosives processing buildings range in construction from small wooden sheds (at the simplest end of fireworks manufacturing), through reinforced concrete cell "egg box" constructions to buried or earth mounded heavily reinforced concrete structures. The first type of structure has the advantage that in the event of an ignition the weak structure relieves easily, and the missiles generated are relatively lightweight. For reinforced concrete cell constructions, the intention is to unitise the risk. Any fire or explosion in one cell should not communicate or propagate to an adjacent cell and should not present a serious risk to persons in the adjacent operations. For these cell-like arrangements it is also important that explosion relief is provided to protect against potential deflagrations. Venting of the explosion in the protective structure should not be to a populated area. This reduces the over-pressure effects both on the structure and occupants. In the event of a fire or explosion inside a cell/egg-box and other types of constructions which have relief via a weak outside wall, the fireball effects, decomposition products and some missiles will be directed with some force towards and through the soft wall, which may also be the direction of the escape route. Whether or not escapees are caught up in these effects will depend upon many factors including the violence of the event, speed of take-up and speed of evacuation. Suitable precautions should be also taken to restrict persons, other than those working in the cells, from these areas and/or, to provide effective barriers. The use of lightweight composite panels as weak walls in explosives processing rooms has been investigated.[25] The design of structures to withstand the effects of accidental explosions is covered extensively in specific literature.[15]

11.1.6 When an explosives process inventory is safeguarded against or from, other adjacent explosives inventories by distance alone, then in the event of an explosion, the blast over-pressure and other effects will depend upon both the separation and the quantity of explosives involved. Clearly the design of the 'receptor' process building(s) will need to take these possible effects into consideration.

11.1.7 Two other important aspects associated with the design of explosives processing buildings are (a) the means of escape in case of fire (see next paragraph) and (b) the possible use of fragment or thermal radiation barriers. If the process building of necessity contains several or more people and accidental initiation of the explosives substance or article in the room could kill or injure most or all of the occupants (by fragmentation and fireball effects), then steps should be taken to minimise these effects by fitting suitable barriers (for example sand bags inside a sealed hardboard enclosure) at strategic positions inside the workroom.

11.2 General Fire Precautions

11.2.1 When designing the layouts etc. of remote manufacturing facilities, it is important to accommodate the appropriate fire precautions.

11.2.2 Under the Fire Certificates (Special Premises) Regulations 1976, explosives factories or magazines licensed under the Explosives Act 1875 and the forthcoming Manufacture and Storage of Explosives Regulations require a fire certificate issued by the Health and Safety Executive. HSE has given guidance on the general fire precautions appropriate to these types of premises.[26]

11.2.3 Worthy of particular mention are the means of escape requirements for pyrotechnics (such as fireworks) processing areas. Depending upon the nature of the pyrotechnics handling operation, each particular process room or building is given an A or B rating. 'Fireworks Process Areas 'A' are those where there are loose or exposed fireworks compositions and 'B' type areas are those where the composition is contained within the body of the firework. Finishing processes where there is a small area of exposed composition on each firework are regarded as Fireworks Process Areas 'B'. Filling of composition into fireworks either manually or by attended machine is regarded as Fireworks Process Area 'A'.

11.2.4 In all fireworks process areas the spread of fire is likely to be rapid. Accordingly the permitted travel distance is very small. From every position in any room or space in a fireworks processing area, persons must have access to unobstructed passageways leading to building exits, without having to travel more than 4m in firework process areas 'A', and 6m in firework process areas 'B'. Dead ends (means of escape in one direction only) are not normally accepted in firework process areas, except for cell ('egg box') type constructions. In these cases the rooms are arranged such that the operator is always positioned between the work bench and the room exit (i.e. no explosives material between the operator and the building exit), and the travel distance to the exit is covered in one or two normal paces.

11.3 Control Room Structure

10.3.1 For large plants, control rooms are likely to be situated in separate buildings, away from the process plant, which they serve. For medium or small plants, control rooms may be within the plant building or control panels may be located local to the plant (see illustrated scenarios at Figure 1). Whatever the location, control rooms should be designed to ensure that the risks to the occupants of the control room are within acceptable limits and that it is suitable for the purposes of maintaining plant control, should the emergency response plan require it, following any foreseeable/undesirable event within the plant.

11.3.2 The most likely threats to the control room are:

- Blast overpressure.
- Blast fragments throw.
- Fires, including jet fires, flash fires and fire balls.
- Smoke and toxic gas releases *(not considered further in this document).*

11.3.3 The threat from fireballs and explosions should be considered in the structural design of the control building. Buildings should be designed to withstand an overpressure that will ensure that risks to individuals within the building are below acceptable limits. Particular attention should be given to the presence of heavy equipment on roofs (e.g. air conditioners) and the ability of internal fixtures to withstand the building shaking. If windows are present in existing structures, then the potential vulnerability of these to blast loading (with subsequent breakage and generation of any high hazard fragments) should be assessed. Consideration should be given to the use of laminated or polycarbonate glass, or preferably eliminating them completely, in order to prevent serious injury to the occupants of the control room in the event of an overpressure. ALARP principles should be applied in these considerations and cost benefit analysis used to determine if additional measures should be applied.

11.3.4 Measures for protection from fires should ensure that the control room will withstand thermal radiation effects and that smoke ingress is controlled. Materials of construction should be fire resistant for the duration of any possible fire event. Smoke ingress may be controlled in a similar manner to toxic gas ingress.

11.4 Specialist Design Standards

11.4.1 An appropriate standard for the design and construction of protective structures for explosive operations is the US Department of Defense standard TM 5-1300. The aim of the standard is to provide protection to personnel, equipment and explosives in one facility (the receptor) from the effects of an accidental explosion in an adjacent facility (the donor).

11.4.2 An introduction in TM 5-1300, suitable for non-specialists, is given for an explosion protection system. This uses a combination of physical safeguards such as containment structures (to prevent an explosion propagating from a donor to a receptor), shelters to provide protection to receptors, barriers between the donor and receptors and segregation by distance. The susceptibility of receptors (personnel, equipment and explosives) to blast and fragments are also detailed and thresholds given.

11.4.3 TM 5-1300 provides the specialist with a means of calculating the effects of blast, fragment and shock loads on structures and the appropriate means of providing protection. Designs are given for reinforced concrete (laced and non-laced structures for walls, slabs, columns and beams), structural steel (framework, panels, blast doors, ventilation closures and fragment shields), masonry walls and blast resistant windows. A building designed to TM 5-1300 and in construction is shown in Figures 4 to 7.

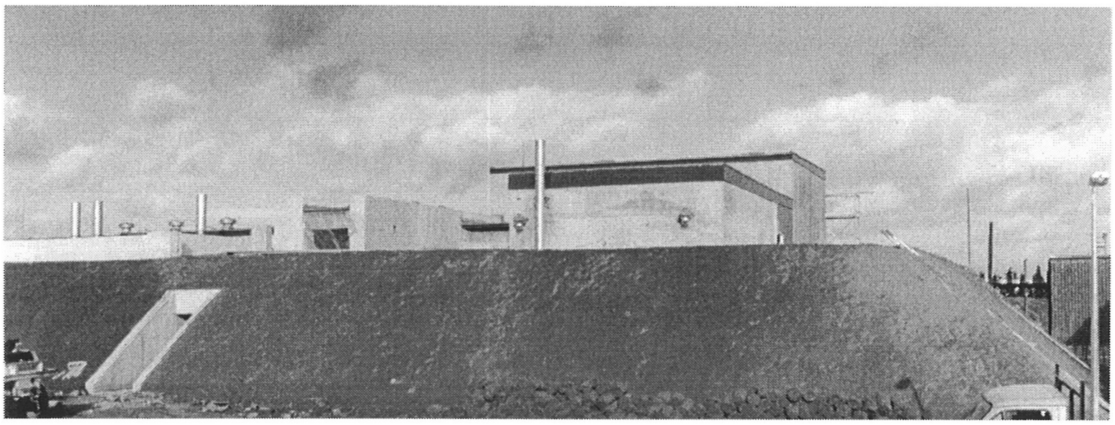


Figure 4: Explosives processing building designed and constructed in accord with the principals of US Department of Defence TM5-1300.

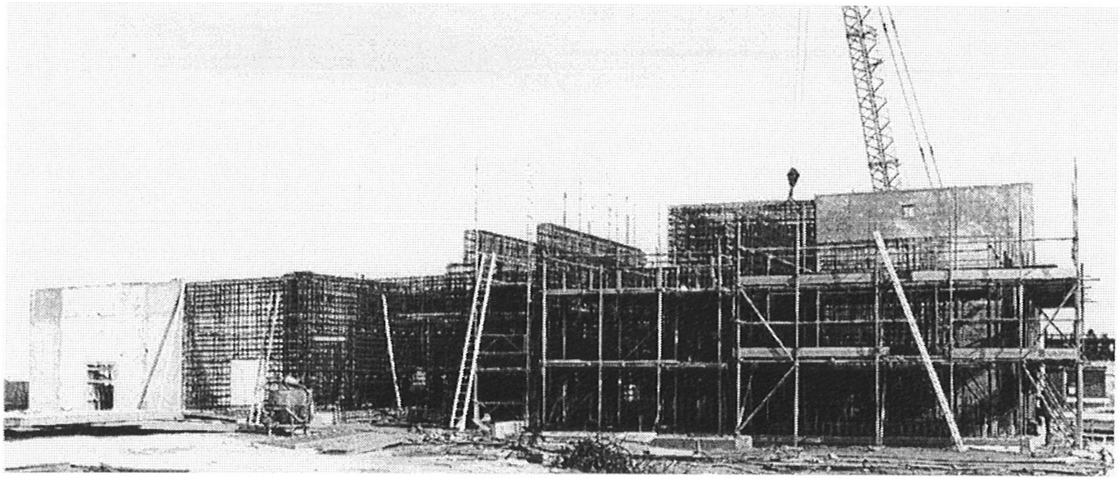


Figure 5: Explosives processing building (previous figure) during construction. Steel reinforcement bars are visible in the walls before cement pouring.

Figure 6: Reinforcement bars in the roof of a cell structure, before cement pouring.

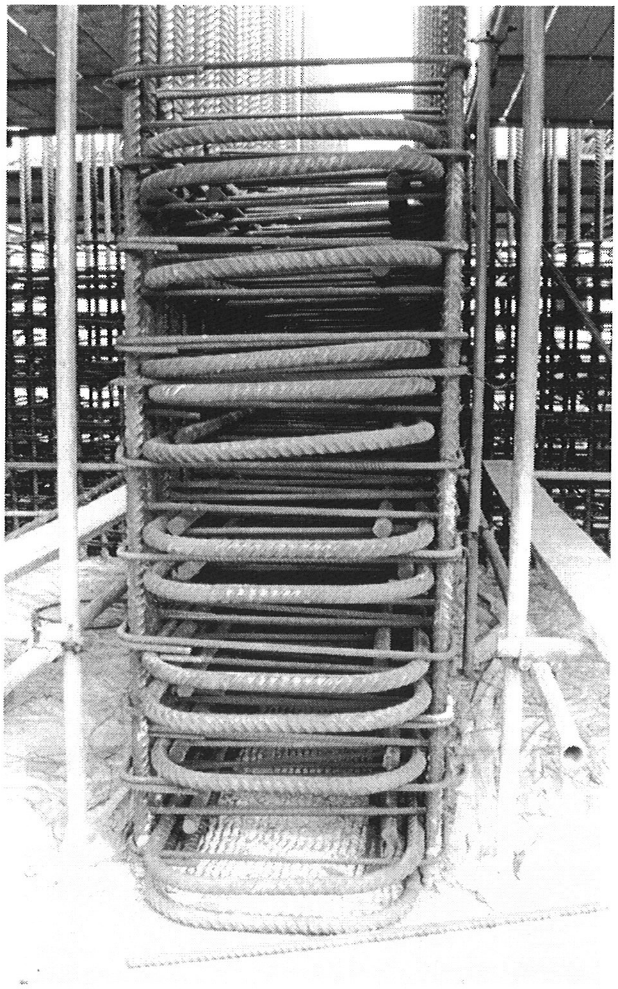


Figure 7: Reinforcement bars in the wall of a cell structure, before cement pouring.

11.4.4 Retrospective application of TM 5-1300 in retrospect to assess an existing explosive facility (where the original design parameters are unavailable), is possible. A structural survey and assessment by a specialist would be necessary. Difficulties may arise with reinforced concrete as the steel reinforcement and lacing of the bars together with the tie in of walls and floors, all critical structural parameters, are encased in concrete and not visible. Covermeter surveys may be used to assess the steel reinforcement pattern (spacing, direction and approximate bar diameter) and the depth of concrete cover to the bars, although invasive surveys are necessary to determine the exact bar sizes as shown in Figure 8. A covermeter functions by generating a magnetic field and detecting changes caused by the steelwork. Core samples from the concrete may be taken to determine the compressive strength and chemical stability. Excavation to reveal the foundations of the base is also necessary.

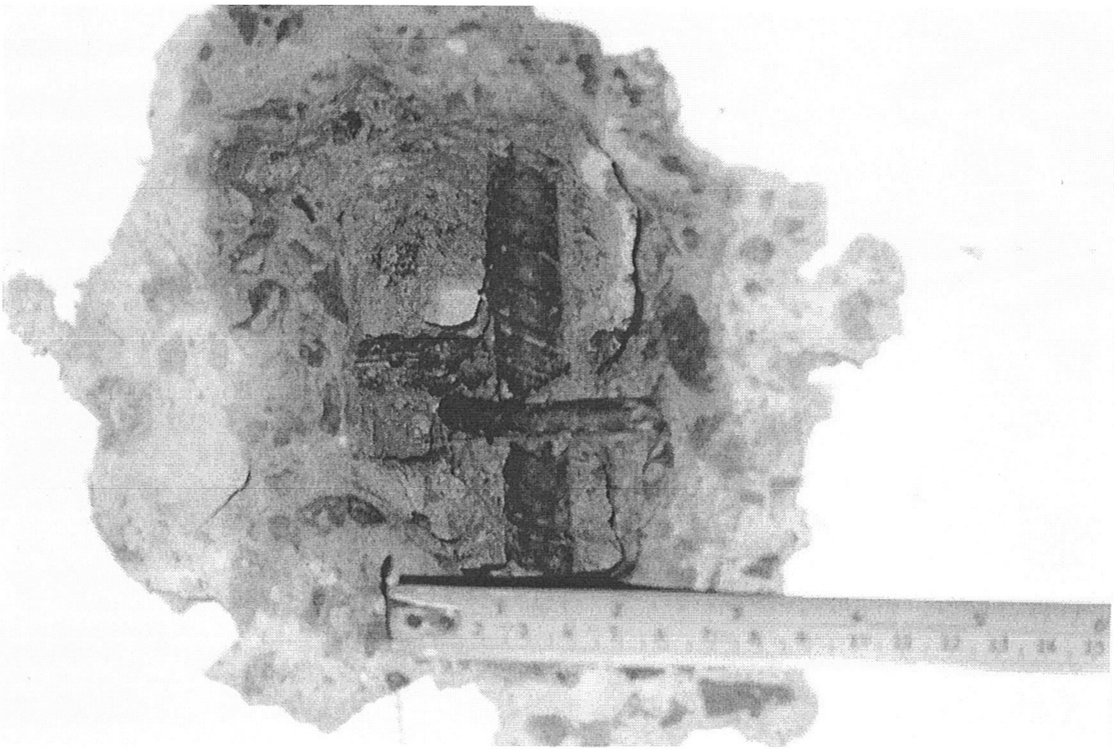


Figure 8: Invasive survey to determine the steel bar sizes of a reinforced concrete slab.

SECTION 12 CONCLUSION

12.1 Some explosives manufacturing operations have a very high risk of an associated fire or explosion. Under such circumstances the process should be conducted remote from the operators. Remote here may mean that the fire or explosion is contained, or that the control room / process area housing people is of robust construction or is at sufficient distance. It is imperative that operators and others are protected from the effects of an accident.

12.2 The need to conduct operations remotely, as opposed to non-remote "hands-on", is determined by a combination of the potential harm from any fire or explosion and the associated likelihood of such an accident, which are assessed by considering a range of factors including the nature and quantity of the explosive substance or article; manufacturing conditions; the rate of energy deposition and the characteristics of the explosives event; and foreseeable process deviations.

12.3 Even where hands-on operations may be appropriate, the ALARP principle applies, where cost is not disproportionate, risk has to be further reduced. Such ALARP considerations may lead to a conclusion that an operation should be conducted remotely.

12.4 Personnel located in control rooms for remote processing operations, or located within the Process Building Distance, should be protected to a pre-determined level. Suitable levels include no structural collapse of the building / room housing people, no blast pressure in excess of the threshold for eardrum rupture, no missiles or fragments sufficient to cause significant injury and no thermal radiation sufficient to cause more than reddening of the skin.

12.5 This guidance has given examples of processes that should be conducted remotely to protect against the effects of blast overpressure, fragments, structural collapse, and thermal exposure. Smoke and toxic fumes have not been considered in this guidance. Engineering controls, such as captive key systems, are used to prevent operators and others from entering process areas at critical times. Process areas may be designed to deliberately vent in a direction away from operators. Escape routes must allow the unimpeded and safe escape from areas of danger.

12.6 Any control room structure must not only withstand the effects of an explosion or fire as outlined above; but it should also be designed to allow ergonomic operation under normal and emergency conditions. An appropriate design code for explosives buildings, including control rooms, is TM 5-1300. Whilst it is normal to apply this code when designing new structures, it is possible to apply it to existing structures, although survey work will be necessary where full construction criteria are not known.

APPENDICES

Appendix 1: **Legislative Requirements**

Appendix 2: **Supplementary Information concerning Hazards from Explosives**

Appendix 3: **Table of Examples of Remote and Non-Remote Processes**

Appendix 1: Legislative Requirements

The aim of this section is to provide a general overview of the key health and safety requirements that apply to explosives manufacture.

There is a considerable amount of health and safety legislation, which has a bearing on the manufacture of explosives. The list below is the principal legislation dealing with activities relating to remote manufacture of explosives:

1. Health and Safety at Work etc. Act 1974

This Act covers the health and safety of people through work activities. It has a number of objectives, primarily to secure the health, safety and welfare of persons at work. It applies to all persons at work irrespective of the work done or the premises where it is done. Under Section 2, employers are required to ensure, so far as is reasonably practicable, the health and safety at work of their employees. Duties placed on employers and the self employed under Section 3 of HSWA are relevant to persons who are not employees, for example contractors. The Act also protects people other than those at work (i.e. the general public) against risks to their health and safety arising out of work activities. The Act imposes duties on everyone concerned with work activities ranging from employers, employees, self-employed, manufacturers, designers, suppliers and importers, people in control of premises and even extends to members of the public.

2. Explosives Act 1875

EA 1875 requires that, with certain exceptions, explosives may only be manufactured in a factory licensed under the Act (licensed factory), and only be kept at a licensed factory, licensed magazine, licensed store, or premises registered under the Act. All licenses and the conditions of registration of premises specify the locations where explosives may be stored (and also in the case of a licensed factory, manufactured), and the maximum quantities and types of explosives, which may be present at each location. Factory and magazine licenses also place limitations on the number of people who may be present at each location.

The General Rules for places licensed or registered under EA 1875, and the model Special Rules for licensed factories and magazines contain requirements relating to safe systems of work.

3. Workplace (Health, Safety and Welfare) Regulations 1992

The requirements of these regulations need to be met to ensure that workplace facilities meet certain standards. There is Health and Safety Executive guidance on these Regulations.[27]

4. Construction (Design and Management) Regulations 1994

The construction industry covers a wide range of activities, hazards, materials, techniques, employment patterns and contractual arrangements. In these circumstances, good management of construction projects from concept through to demolition is essential to maintain health and safety standards.

CDM is intended to protect the health and safety of people working in construction, and others who may be affected by their activities. The Regulations require the systematic management of projects from concept to completion: hazards must be identified and eliminated where possible, and the remaining risks reduced and controlled. This approach reduces risks during construction work and throughout the life cycle of a structure (including eventual demolition).

There is Health and Safety Executive guidance on these regulations.[28]

CDM and the Construction (Health, Safety & Welfare) Regulations 1996 are currently undergoing extensive review. Consultation on proposals is expected during 2005

5. Provision and Use of Work Equipment Regulations 1998

PUWER applies to the provision and use of all work equipment, including mobile and lifting equipment, and to all workplaces and work situations where HSWA applies. The Regulations define work equipment as "any machinery, appliance, apparatus, tool or installation for use at work (whether exclusively or not)".

There is an approved code of practice and guidance for PUWER.[29]

6. Management of Health and Safety at Work Regulations 1999

An important requirement of these regulations is for an employer to make a suitable and sufficient assessment of the risks to the health and safety of employees and other persons arising from the employer's undertaking in order to identify the measures the employer needs to take to comply with health and safety legislation. Similar duties are placed on the self-employed. These regulations also (in Schedule 1) lay down a set of principles to be followed in identifying the appropriate protective measures to control the risks identified by the risk assessment. There is an approved code of practice and guidance for these regulations.[30]

7. Control of Major Accident Hazards Regulations 1999

These regulations apply to any establishment, which has, or anticipates having, any substance specified in Schedule 1 to COMAH above the qualifying quantity. At establishments where COMAH applies, advice in the guide will be relevant to various aspects of the general duty under the regulations for the operator of the establishment to take all measures necessary to prevent major accidents and limit their consequences to people and the environment. There is Health and Safety Executive guidance on these Regulations.[31]

COMAH is currently under review, with the aim of implementing the Seveso II amending Directive (2003/105/EC) in a revised set of Regulations sometime during 2005. The revision will include a reduction in the COMAH qualifying dangerous substances thresholds, which include explosives.

8. Dangerous Substances and Explosive Atmospheres Regulations 2002

These regulations apply to all dangerous substances at nearly every business in Great Britain. They set minimum requirements for the protection of workers from fire, explosion and similar (energy releasing) events, which are caused by dangerous substances and potentially explosive atmospheres. The regulations are complementary to the general duty to manage risks under the Management of Health and Safety at Work regulations 1999. The main requirements are that employers and the self-employed must:

- Carry out a risk assessment of work activities involving dangerous substances
- Provide technical and organizational measures to eliminate or reduce as far as is reasonably practicable the identified risks
- Provide equipment and procedures to deal with accidents and emergencies
- Provide information and training to employees
- Classify places where explosive atmospheres may occur into zones, and mark the zones where necessary.

9. Manufacture and Storage of Explosives Regulations 200-

These will replace most of the remainder of the Explosives Act 1875 and 1923 and subsidiary legislation. The Regulations are currently expected to come into force in 2005.

The central provisions of the Regulations are the need to:

- prevent unplanned fire or explosion
- limit extent and spread of fire and extent and communication of explosion from one location to another
- protect persons from the effects of fire or explosion.

10. Supply of Machinery (Safety) Regulations 1992

These Regulations define the requirements on suppliers of machinery for product safety.

11. Fire Certificate (Special Premises) Regulations 1976

The purpose of these Regulations is to ensure adequate provision of general fire precautions in explosives factories and magazines. They cover construction and layout in buildings, provision of means of escape, fire fighting equipment and fire warning systems, together with the training of staff and establishment of emergency arrangements to be followed in case of fire.

12. Fire Precautions (Workplace) Regulations 1997 (as amended 1999/2003

These regulations make requirements for fire fighting, fire detection, emergency routes and exists, maintenance of the workplace and safety devices, risk assessment, health & safety arrangements, health & safety assistance, information for employees, coordination and co-operation and persons working in host employers' undertakings.

13. Regulatory Reform (Fire Safety) Order 200-

Fire safety within the UK is currently undergoing a major change. The Regulatory Reform (Fire Safety) Order is set to change the emphasis from fire certification to the fire risk assessment goal based principle and self-regulation.

The aim is to create one fire safety regime that applies to all workplaces and other non domestic premises. The current system of fire safety in the UK involves over 100 pieces of fire legislation.

The RRO will be risk assessment based with responsibility for fire safety of occupants of a building, and those who may be affected by a fire, resting on the responsible person. (the employer).

The Fire Precautions Act 1971 and the Fire Certificate (Special Premises) Regulations 1976 are set to be repealed/revoked and the fire certification process removed. The Fire Precautions (Workplace) Regulations 1997 (as amended) and the Dangerous Substances and Explosive Atmosphere Regulations 2002 are set to form the basis for the Fire Safety Order.

Fire authorities will continue to inspect premises and enforce the regulations. The HSE will continue to be the enforcing authority for fire safety where they licence explosives factories and magazines.

Appendix 2: Supplementary Information concerning Hazards from Explosives

High Explosives

1. The principal explosion hazards associated with high explosives result from blast waves and fragments that may arise from any container or adjacent structure. A full quantification of these effects is outside the scope of this document, but some indication of the potential involved is given by considering the effects of explosions of small quantities of high explosives inside a small single storey (6m x 6m) building:-

<u>1g of Explosive:</u>

• any person holding the explosive could receive serious injury.

<u>10g of Explosive:</u>

• any person close to this quantity of explosive at the time of initiation would receive very serious injuries. 1% of persons at a distance of 1.5 metres away are also liable to ear-drum rupture.

<u>100g of Explosive:</u>

• 50% of windows in room likely to be blown out.
• 1 % ear-drum rupture at distance of 3.5m.
• 50% ear-drum rupture at distance of 1.5m.
• persons in very close proximity to explosion (e.g.. holding the explosive) almost certainly killed.

<u>500g of Explosive:</u>

• complete structural collapse of brick-built building is most likely.
• steel or concrete framed building would probably survive.
• persons very close to blast almost certainly killed.
• persons close to blast will be seriously injured by lung and hearing damage, fragmentation effects, and from being thrown bodily.
• almost all persons within the room will sustain perforated ear-drums.

Pyrotechnics

2. The burning characteristics of pyrotechnic substances generally range from slow to very violent burning. Under certain conditions some high energy pyrotechnic substances can detonate. German legislation controlling the manufacture of pyrotechnics requires individual manufacturers to assign their pyrotechnic compositions, semi-finished products and finished articles into five groups according to their sensitiveness and burning characteristics. At the slow burning end of the range, Group 5, the compositions burn slowly and articles either burn or explode singly. At the opposite end, Group 1, the compositions burn very violently and even without confinement small quantities can explode. Also they are mechanically and thermally

very sensitive and Group 1 articles are capable of mass explosion. Examples of both composition and article assignments are as follows:-

GROUP 1:

<u>Compositions: (burn very violently)</u>
Chlorate and metal perchlorate report or whistling compositions.
Dry non-gelatinised cellulose nitrates.
Barium peroxide/Zirconium compositions.

<u>Articles: (mass explosion risk)</u>
Flash shells (maroons).
Casings containing flash compositions.
Sealed hail preventing rockets.

GROUP 2:

<u>Compositions: (burn violently)</u>
Nitrate/metal/sulphur compositions.
Compositions with >65% chlorate.
Black powder.
Nitrate/boron compositions.

<u>Articles: (accelerating single-item explosions)</u>
Large firework shells.
Fuse unprotected signal flares.
Non-pressed report bullets (bird scarer).
Report cartridges, unpacked.
Black matches, uncovered.

GROUP 3:

<u>Compositions: (burn fast)</u>
Nitrate/Metal compositions without sulphur.
Compositions with up to 35-65% chlorate.
Compositions with black powder.
Lead oxide/silicon with >60% lead oxides.
Perchlorate/metal compositions other than report.

<u>Articles: (burn very violently with single-item explosions)</u>
Large firework shells.
Fuse protected signal flares.
Pressed report cartridges in primary packagings.
Quickmatches in transport packagings.
Waterfalls; Silver wheels; Volcanoes.
Black powder delays.

GROUP 4:

<u>Compositions: (low/medium speed burning)</u>
Coloured smoke compositions.
White smoke compositions (except those in Group 5)
Compositions with <35% chlorate.
Thermite compositions.
Aluminium/phosphorous pesticide compositions.

<u>Articles: (single-item ignitions/explosions)</u>
Large firework shells without flash compositions in transport packagings.
Signal ammunition without flash compositions, up to 40g of composition.
Small fireworks, fuse protected (except volcanoes and silver wheels).

GROUP 5:

<u>Compositions: (burn slowly)</u>
Slow burning heating compositions.
White smoke compositions based on hexachloroethane with zinc, zinc oxide and <5% of aluminium, or <10% of calcium silicon.

<u>Articles: (slow single-item ignitions/explosions)</u>
Small fireworks in primary packagings.
Signal ammunition in transport packaging.
Delays without black powder.
Coloured smoke devices.
Sealed table bombs.
White smoke devices unpacked (see Group 5 composition).

3. For each type of processing or storage activity, and for each type of pyrotechnic, German regulations prescribe how the pyrotechnic should be handled, including maximum quantity per room and number of occupants. The greatest restrictions are placed upon Group 1 explosives and articles. To reproduce here lists of groupings for specific formulations and articles, together with the corresponding restrictions that apply in Germany, would occupy several pages and probably not accord completely with UK products. The examples given here of the groupings are useful though both in demonstrating the vast range in burning behaviour of these materials, and an indication of the likely behaviour of generic types.

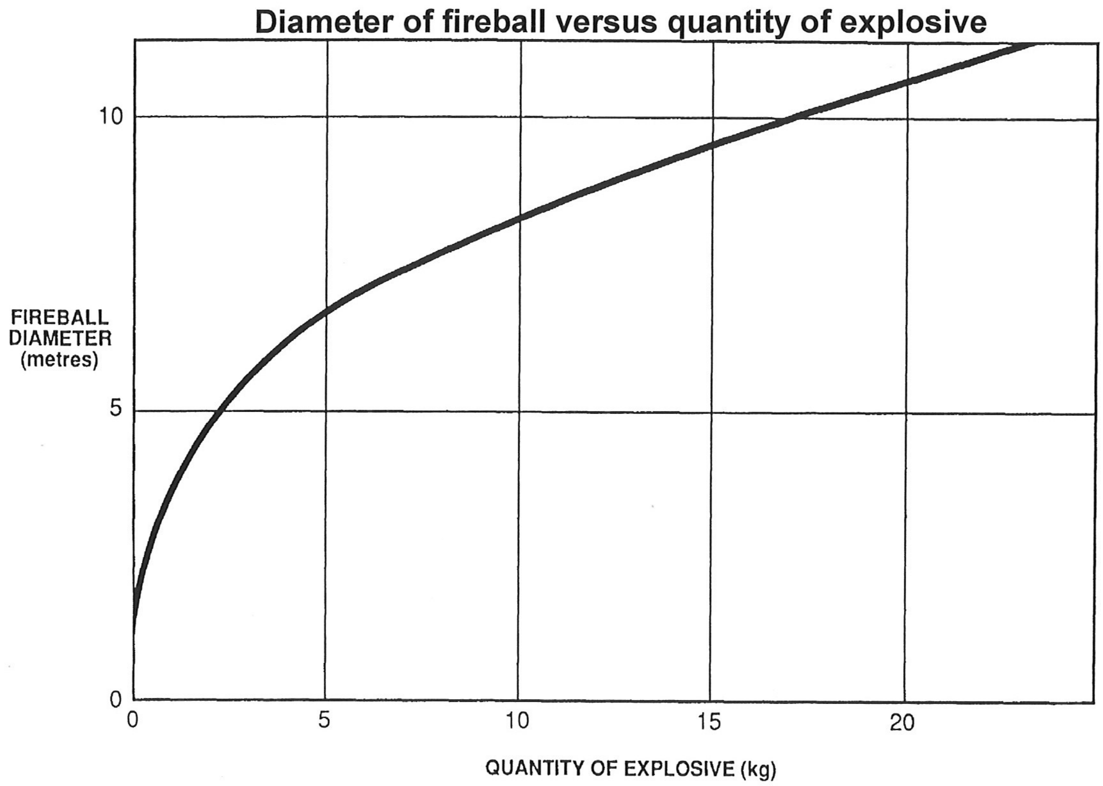
4. It is important to understand the possible behaviour of small quantities of pyrotechnic substances or a single article, and the possible effects of self-confinement. Bundles of pyrotechnic articles (e.g. fireworks) may burn much more vigorously and even violently (with sufficient numbers of items) than single items. If any doubts exist about the way a particular substance will behave, in the quantities and configuration that it is intended to work, it will be necessary to either use a remote manufacturing facility, or arrange for full-scale remote trials to be conducted to demonstrate "safe" behaviour.

5. An estimate of the size of fireball from a "fast" burning pyrotechnic, high explosive or propellant is given by the expression:- [32]

$$D=3.77Q^{1/3}$$

D is diameter of fireball in metres.
Q is weight of substance in kilograms.

Thus 2kg of pyrotechnic composition might be expected to give a fireball of diameter 5m. A graph showing quantity (kg) of explosive versus fireball diameter (m) is given below.



6. Persons engulfed within a fireball and not wearing fire resistant protective clothing, are likely to receive very serious bums. Persons in close proximity to the fireball are also vulnerable, depending upon size and duration of the event. Methodologies are available for estimating likely burn injuries.[33,34]

Propellants

7. The potential hazards from propellants are generally very similar to those from pyrotechnics, i.e. vigorous burning and fireball effects are typical; - see previous paragraph for fireball diameter estimates. Confinement, however, has the effect of increasing the burning velocity of propellant materials and with sufficient confinement, detonation occurs on initiation. Situations in practice that might encourage this transition from burning to detonation, might be where propellant is processed in relatively large quantities and in equipment which provides significant confinement.

Appendix 3: Table of Examples of Remote and Non-Remote Processes

Note: The decision on the selected process should be based upon the result of a thorough risk assessment of the activity to be undertaken. The examples shown below may not be appropriate for all circumstances.

Process	Typical Equipment	Protection		Comments & Known incidents
Synthesis				
Nitroglycerine manufacture	Centrifuge, static separator	Remote		Many events world-wide
Formulation / Preparation				
Preparation of new / novel formulations	Small scale. Safety screen, conducting conditions, eye protection, and leathers gauntlets.		Non-Remote	
Mixing of initiator compositions	Turbular mixer/drum, jelly mould	Remote		
Mixing/Incorporation of pyrotechnic compositions	Turbular mixer/drum, jelly mould	Remote		
Mixing/Incorporation of NG-based propellants	Incorporator	Remote		
Mixing/Incorporation of blasting explosives	Incorporator	Remote		
Mixing and pouring PBX	Planetary mixers	Remote		
Mixing of secondary HE / PBX formulations	Anchor stirrer mixers		Non-Remote	
Mixing and extruding HE		Remote		
Manufacture of ANFO	Inclined Elevator / Blender		Non-Remote	
Manufacture/Mixing of Slurries	High speed rotary mixer	Remote		
Manufacture/Mixing of Water Gels	High speed rotary mixer	Remote		
Manufacture/Mixing of AN Emulsions	High shear mixer	Remote		

Process	Typical Equipment	Protection		Comments & Known incidents
Collecting Product: Filtering / Drying / Precipitation				
Precipitation, drying and sieving of initiator compositions		Remote		
Sieving of sensitive pyrotechnic powder, e.g. flash powder		Remote		
Drying pyrotechnics			Non-Remote	
Sieving secondary HE	Sieve		Non-Remote	
Drying PETN	Turner Plough	Remote		
Drying HE	Ovens		Non-Remote	
Testing, Analysis & Proofing				
Differential Thermal Analysis, Differential Scanning Calorimeter, Thermal Gravimentric Analysis	DTA, DSC, TGA.		Non-Remote	Very small quantities. Damage to equipment, e.g. to balances, heating pans
Small scale tests	F of I, mallet friction, mallet impact, electrostatic spark,		Non-Remote	
Bomb Calorimetry	Bomb Calorimeter	Remote		
Vacuum Stability Test, Chemical Compatibility Test			Non-Remote	
Trough / Train Test. Temperature of Ignition Test	Metal trough, bomb cabinet	Remote		Explosion
Small scale trials on propellants			Non-Remote	Protect from flame

Process	Typical Equipment	Protection		Comments & Known incidents
Surface area measurement, Density of pyrotechnic (Small scale)			Non-Remote	
Surface area measurement; Density of HE	Balance, measuring cylinder & rod for Tap Density of powders, Coulter Counter		Non-Remote	
X-ray of HE charges	X-ray	Remote	Non-Remote	Remote not required where x-rays are enclosed, low power (c.f. airport scanners)
Dimension measurement of HE charges	Co-ordinate Measuring Machine		Non-Remote	
Climatic storage, accelerated ageing	Thermal chambers. QD rules.		Non-Remote	
Mechanical properties tests, compression, tensile, 3-point bend, Brazilian disc, creep test etc	E.g. Universal mechanical test machine, e.g. Instron, Lloyds		Non-Remote	
Firing and test ranges		Remote		Operator lost finger in non-remote activity
Medium scale hazard tests on HE	LABSET, ODTX, gas gun impact trials	Remote		
Large scale hazard trials on HE	Jabroc Oblique Impact, Oblique Impact, Drop, Susan Test Vehicle, Confined Heating, Bullet Attack, Bonfire	Remote Bunker on Range		
Processing				
Manufacture of primer caps		Remote		Frequent explosive incidents
Detonator manufacture lines		Remote		
Pelleting of pyrotechnic compositions	Rotary press	Remote		Ignition in press propagating to the hopper

Process	Typical Equipment	Protection		Comments & Known incidents
Pressing candles, rockets, gerbs, fountains		Remote		
Pressing MTV flares		Remote		
NC/NG paste manufacture		Remote		
Pressing and extruding double base propellant	Vertical or horizontal presses, mixer extruders.	Remote		Ignition in press
Cutting double base propellant	Rotary cutters	Remote		Ignition of powder on cutting. Protected and vented enclosure
Rolling of propellant			Non-Remote	Fire and fatality in non-remote facility.
Incorporating propellant dough	Incorporator	Remote	Non-Remote	Incorporator fires
Curing polyurethane based propellants			Non-Remote	
Propellant machining, milling and grinding	Lathe, mill and grinder	Remote		Fire whilst machining
Core removal from HTPB propellant	Core extraction	Remote		
Milling of RDX/HMX		Remote		
Particle size reduction of PETN, TATB	Mill. Hydrocyclone	Remote		
Curing of polyurethane based HE	Ovens		Non-Remote	
Blending batches of secondary HE	Tray, rakes, scoops		Non-Remote	
Cartridge filling water gels / slurries			Non-Remote	
Pelleting of secondary HE / PBX powders	Die press	Remote		Explosions reported in US where re-application of pressure (design & fault conditions)

Process	Typical Equipment	Protection		Comments & Known incidents
Pelleting HE (e.g. RDX/wax) powders	Rotary press	Remote		Ignition in press propagating to the hopper
Pressing charges HE powders	Isostatic press	Remote		
Pressing secondary HE into detonators	Pneumatic press (high density fill) & hand press (low density fill) with explosives safety screen		Non-Remote	(Small quantities of explosive contained in pneumatic press or fragments captured by screen.)
Parylene coating of HE charges	Coating machine		Non-Remote	
Bandsaw cutting of HE charges	Bandsaw	Remote		
Bandsaw cutting of HE shells	Bandsaw	Remote		Ignition of a charge
Cavity boring of HE filling (e.g. 155mm shells)	Boring equipment	Remote		
Machining HE charges	Mill	Remote		
Drilling / turning HE charges	Lathe	Remote		
Machining TATB		Remote in UK		Contact in some US labs, where TATB classified 1.5 or 1.3
Disposal / Destruction				
High pressure water jet cutting of propellant	Pressurised water jet	Remote		Fire
Explosive contaminated equipment cleaning (vapour cloud explosion)	Medium pressure jet of cleaning fluid (plasticiser)	Remote		Made remote following incident
Burning ground disposal	Open burning	Remote		Fatalities and injuries
Burning ground disposal	Incinerator	Remote		(Remote unless incinerator contains explosion)

ABBREVIATIONS

EA 1875	Explosives Act 1875
HSWA	Health and Safety at Work etc Act 1974
CDM	Construction (Design and Management) Regulations 1994
PUWER	Provision and Use of Work Equipment Regulations 1998
COMAH	Control of Major Accident Hazards Regulations 1999
MHSWR	Management of Health and Safety at Work Regulations 1999
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations 2002
MSER	Manufacture and Storage of Explosives Regulations 200-
SMSR	Supply of Machinery (Safety) Regulations 1992

ALARP	As Low As Reasonably Practicable
AN	Ammonium Nitrate
ANFO	Ammonium Nitrate Fuel Oil
DSC	Differential Scanning Calorimetry
DTA	Differential Thermal Analysis
F of I	Figure of Insensitiveness
HD	Hazard Division
HE	High Explosives
HMX	Octogen / Tetramethylene tetranitramine
HSE	Health and Safety Executive
HT	Hazard Type
HTPB	Hydroxy terminated polybutadiene
LABSET	Laboratory Scale Explosiveness Test
MTV	Magnesium Teflon Viton
NC	Nitrocellulose
NG	Nitroglycerine
ODTX	One Dimensional Time to Explosion
PBX	Plastic / Polymer Bonded Explosives
PETN	Pentaerythritol tetranitrate
QD	Quantity Distance / Separation Distance
RDX	Hexogen / Trimethylene trinitramine
TATB	Triamino trinitrobenzene
TGA	Thermo-Gravimetric Analysis
UN	United Nations

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ACKNOWLEDGEMENTS

The HSE / CBI Explosives Industry Group partnership working together on the Explosives Industry Forum wish to gratefully acknowledge the following organisations for their valuable effforts made in the preparation and production of this guidance:

HSE Explosives Inspectorate
AWE plc
BAE Systems