Report of the Independent Investigation into the Fire in Building on 3rd August 2010

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EXECUTIVE SUMMARY

At approximately 21:00 on Tuesday the 3^{rd} August 2010, a fire broke out in building . The fire caused damage to the equipment and materials inside the building and to part of the building fabric. The fire occurred during a lacquer preparation process, which involved the addition of dry nitrocellulose (NC) to containers of the solvent Methyl Ethyl Ketone (MEK). An explosive mixture which was being simultaneously prepared in an adjacent part of the building was not compromised by the fire. At the time of the incident four members of staff were working in or around the locality of , and one operative sustained a minor burn.

An independent investigation was set up to identify the direct and root causes of the fire and to evaluate the effectiveness of the emergency response activities. This report represents the findings and recommendations submitted to the AWE Chief Executive Officer (CEO) by the investigation team.

The investigation determined that the most probable direct cause of the fire was ignition of the MEK due to electrostatic discharge from within the dry NC, which occurred as the NC passed through the flammable layer of solvent in the lacquer preparation container. Once the MEK had ignited, other combustible materials in the building acted as fuel to maintain the fire. There is also a possibility that the NC drying process could have caused some self-heating leading to the generation of chemical substances that are incompatible with MEK. The occurrence of a fire on this particular occasion is concluded to have been due to an alignment of a number of process variables, which came together to allow initiation and propagation.

The root cause of the incident was attributed to a lack of knowledge of detailed properties of the materials used in the lacquer preparation process and their interaction, in particular NC and MEK. These shortcomings led to insufficient attention to lacquer preparation and related electrostatic discharge issues in the hazard identification and risk assessments.

The investigation also made a number of other observations which, whilst not directly impacting on the fire, require management attention. These included:

- Presence of High Explosives (HE) in the building, as a result of the early preparation of a batch of lacquer whilst a batch of HE was still being mixed; and
- A lack of adequate process reviews to challenge existing practices in the lacquer preparation process.

In addition, there were non-compliances with Operating Instructions, Explosives Safety Orders (XSOs) and planned work schedules which further weakened the barriers to an event involving explosives.

A review of the emergency response activities determined that an overall satisfactory outcome was achieved, with a number of learning points for future incident management.

Eleven recommendations have been made, which can be found in Section 10, including two relating to improvements in emergency response arrangements.

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1 INTRODUCTION

At approximately 21:00 on Tuesday the 3rd August 2010, a fire broke out in building . The fire caused damage to the equipment and materials inside the building and to part of the building fabric. The fire occurred during a lacquer preparation process, which involved the addition of dry nitrocellulose (NC) to containers of the solvent Methyl Ethyl Ketone (MEK). An explosive mixture which was being simultaneously prepared in an adjacent part of the building (as part of the manufacture of a High Explosives (HE) moulding powder) was not compromised by the fire.

At the time of the incident four members of staff were working in or around the locality of , and one operative sustained a minor burn. Upon notification of the incident to Site Control, site emergency response procedures were initiated, including attendance of off site services. A safety cordon of 600 metre was established around the building due to the presence of explosives. This extended beyond the site boundary and required the closure of some external roads and the evacuation of a number of local residents.

2 OBJECTIVE

An independent investigation was set up with the objective of identifying the direct and root causes of the fire, and submitting a report of the findings and recommendations to the AWE Chief Executive Officer (CEO).

3 SCOPE

This report responds to the requirements of the Terms of Reference for the independent investigation (refer to Annex A).

The report relates only to the events directly associated with the incident occurring on the 3rd August 2010, and the immediate emergency response activities. It does not cover any of the subsequent make safe, clean up or restart operations.

4 INVESTIGATION TEAM

The incident investigation was conducted by a team of AWE technical experts and Environment, Health and Safety (ESH) specialists, supported by a technical investigation team led by the Company The investigation was chaired by an independent, external member of the Nuclear Safety Committee (NSC).

Representation on the team included:

Investigation Team Leader	Explosives & Safety Specialists
	Fire Officer
Internal Regulators	Environmental Specialist
Site Control	Trade Union Representatives

5 METHODOLOGY

The team met daily to discuss progress, incident findings, further lines of enquiry and required actions.

A fault tree analysis process and fishbone diagram was used to identify all potential sources of ignition (direct cause of fire) and indirect (root) causes of the incident.

Information sources reviewed included:

- Photographs and videos of the incident scene;
- Interviews of individuals and witnesses involved in the incident and process being undertaken;
- Interviews of incident responders;
- Safety management system documentation including risks assessments, operational instructions etc;
- Test results of chemical analyses; and
- Report of the post fire building inspection.

6 BUILDING & PROCESS DESCRIPTION

6.1 Building

is a process building located within the explosives area on the Aldermaston site, which does not handle nuclear material. It forms part of the Assembly and Explosives Operations (AXO) Asset within the Production Operations Directorate, which provides capability for the manufacture, research, development and testing of explosives and non-explosive substances and articles.

has an Explosives Building Schedule which forms part of the AWE Aldermaston Explosives Site Licence issued by the Health and Safety Executive (HSE). Prior to the incident it was used for processing both explosives materials and non explosive materials associated with the manufacture of explosive moulding powders.

The building has a main room incorporating an enclosure containing a 60 gallon mixing pan for the preparation of explosives moulding powder. The enclosure is fitted with a local exhaust ventilation (LEV) system. In the main process area there is a 5 gallon and 10 gallon mixing pan both of which are connected to the LEV.

6.2 Lacquer Preparation Process

Preparation of NC lacquer is a key step in the manufacture of explosives moulding powder. The product has been manufactured since the late 1970s to support programme demand and exercise manufacturing capability. In order to demonstrate this capability, and remove the need for product re-qualification, the process is performed approximately every 12 – 18 months.

The lacquer preparation process involves dissolving dry NC in the solvent 2-butanone, commonly known as MEK. The process requires NC, which is stored wetted with isopropyl alcohol (IPA), to be dried before adding to the MEK. This is achieved by heating in a mixing pan until judged to be dry. The specified drying temperature is 90°C ± 5 °C.

The lacquer is prepared by adding 375 g of dry NC to 18 litres of solvent in 24 litre polythene mixing containers, referred to as 'bins'. Four bins are needed for a typical 150 kg batch of explosives moulding powder, which is produced by mixing the lacquer with the explosive HMX. The process has been performed many times before, most recently on the day before the fire. The incident occurred during the addition of NC to the first of three MEK bins which had been filled for the 150 kg batch; the remainder of the preparation process was not completed.

6.3 Materials

6.3.1 Methyl Ethyl Ketone (MEK)

MEK is used widely as a solvent for manufacturing and cleaning operations and is classed as a flammable liquid. Its vapour can form flammable mixtures with air which can be ignited by sources such as naked flames or electrical discharges. The combination of these properties requires workplaces to be well ventilated and sources of ignition need to be eliminated or controlled.

The MEK used for the lacquer preparation was analytical reagent grade, which was stored outside the facility in two 205 litre metal drums. The material had been stored for approximately two years in the external solvent store and one of the drums had first been opened around a year before the incident.

6.3.2 Nitrocellulose (NC)

NC is a nitrate ester manufactured by nitration of cellulose, usually cotton or wood pulp in origin. During storage NC is desensitised by wetting with IPA (UN classification: 0340); however, it remains a considerable fire hazard. Dry NC (UN classification 2256) easily develops a significant electrostatic charge and is vulnerable to ignition by electrostatic discharge, friction, heat or impact. Once ignited the material burns very rapidly.

In the mid 1990s the supplier of the lacquer grade NC used by AWE ceased production. To extend the storage life of the existing stock of NC, the material has been held chilled at – 18 °C to reduce the rate of degradation. The material is subject to annual surveillance testing, the purpose of which is to confirm its continuing stability and suitability for use.

7 THE EVENT

The following is a commentary on the events leading up to the fire which has been constructed from witness evidence, and a description of the likely processes occurring. Timings and the sequence of events have been summarised in Table 1.

After removal from storage, the IPA wetted NC was placed in a mixing pan and heated at approximately 83 °C for 49 hours to remove the IPA. The NC would have been turned periodically by hand to aid drying. Drying was completed at 13:00 on Wednesday 28th July. The NC was then removed, placed in a polythene bag, transferred to a wooden box and stored for subsequent use in lacquer manufacture.

On Monday 2nd August, a batch of NC lacquer was successfully prepared for onward use in the explosive moulding powder manufacture process. During the preparation, one operative reported observing that the mixture had a 'pink tinge'. This pink tinge was not corroborated by the Team Leader who completed the second half of the lacquer preparation, and described the mixture as having a 'straw like' appearance. Whilst the exact nature of the colouration may be subjective, it is possible that it may have been associated with the presence of trace impurities in one of the ingredients; this is not regarded as a contributory factor in the incident.

On Tuesday 3rd August a batch of explosive moulding powder was made successfully and was heated and mixed in the ventilated enclosure.

During the evening, preparation of NC lacquer for the next batch of moulding powder began in the work area outside the enclosure. Although there was no forced ventilation of this work area, there was some air flow through the doors of the enclosure due to the LEV on the large mixing pan.

Three bins had each been filled with 18 litres of MEK; one 'Jerry can' of MEK was present in preparation for filling the remaining bin. Two of these bins had their lids fitted.

The operative preparing the bins was wearing conducting shoes, non-conducting coveralls and nitrile gloves and a respirator. He weighed out a 375g 'bundle' of NC into a polythene bag, leaving the remaining NC in a bag next to the scales (estimated to be approximately 1.9kg). He then began to tear off small (1-2 cm) pieces from the bundle and dropped them into the MEK in the bin.

After less than about 100 g had been added the operative observed something unusual and walked away from the bin, placing the remaining material back into the bag.

The operator reported seeing a very bright orange glow and flash and hearing a loud noise. He observed that the bin was on fire. The operatives departed the building and headed towards the emergency building in

A few minutes later the Fire & Rescue Service attended and reported seeing a 'bucket fire'. The fire then continued to burn until all available combustible materials had been consumed. The explosive mixture in the enclosure was protected from the effects of the fire and was not consumed.

Date	Time	Description	Source
26/07/10	12:00	NC drying commenced.	Process work sheets
28/07/10	13:00	NC drying completed (at temperature of 80 °C for 49 hours).	
02/08/10	-	NC weighed out into 375 g bags	Witness statements
		4 bins of lacquer prepared	
03/08/10	07:30	Workers arrive and first batch of moulding powder manufacture commences in the enclosure.	
	11:00	Addition of ingredients completed and mixing started. One operative departs for AWE Burghfield to work on explosives pressing.	
	12:00	Heat applied to mixing pan. One further operative leaves site.	
	16:30	Operative returns from AWE Burghfield. Two operatives go home leaving 4 in support of the process. Remaining staff meet in the building.	
	Post 18:00	Decision made by Team Leader to make lacquer for next batch.	
	20:30	Two operatives sent to fetch demineralised water. Remaining operative and Team Leader filled 3 bins of MEK from external storage drums.	
	21:00	Operative added small quantities of NC to the first bin of solvent. He reported that "*something didn't feel right*" and stopped adding the NC (at this point approximately 100 g had been added). He put the remaining NC back into the bag and went to the table a few metres away and removed his respirator. A fire began with a flash appearing to emanate from the vicinity of the bin. Staff evacuated to the nearby emergency building	
	21:06	Emergency call received at Fire Station.	
	-	The operatives stated they felt uncomfortable in the emergency building, due to the presence of explosives and still being inside the potential blast area, so they left the building and drove to gate 12 to exit the facility compound.	
	21:15	Firemen arrived at the building and reported observing a 'bucket fire'. The fire developed rapidly engulfing the front face of the building.	

Table 1. Sequence of Incident Events

8 INVESTIGATION FINDINGS

This section presents the findings of the investigation into the circumstances surrounding the fire in .
Section 8.1 describes the most likely physical cause of the event as concluded in the technical investigation, led by the This is based on analysis of the materials involved in the lacquer preparation process, data from technical literature and advice from external bodies.

Sections 8.2 and 8.4 consider the adequacy of the hazard and risk analysis of the lacquer preparation process; how the output from these influenced procedural and engineering controls; and whether these controls were in place and effective. Section 8.5 concerns personnel competency, the organisation and deployment. Finally, Section 8.6 considers whether information available, either internal or external to the organisation, if acted upon, could have prevented the incident.

Each section ends with an evaluation; these are brought together in Section 10 to form the overall conclusions on the direct and root causes of the incident.

8.1 Physical Causes

A technical investigation team with expertise in explosives safety, electrostatics and chemistry was formed to explore the physical causes of the fire. The team used a structured problem solving methodology to systematically identify and evaluate possible causes of ignition.

As discussed previously, the materials involved with the incident were MEK and dry NC. MEK is a highly flammable solvent with a low ignition energy (0.53 milli-Joule) making it highly sensitive to ignition by electrostatic discharge. Although it has a low flash point at – 7 °C the auto-ignition temperature is relatively high at 404 °C. Dry NC is an energetic propellant that is known to readily accumulate electrostatic charge. It is sensitive to ignition by shock, friction, heat, electrostatic discharge and auto-ignition.

Fundamentally, energy has to be supplied to ignite the materials present and possible sources of energy include:

- Electrical:
  - Electric current (from mains supply or equipment);
  - Electrostatic discharge;
- Electromagnetic radiation;
- Chemical reaction:
  - Incompatibility;
  - Reactive impurities;
  - Reactive degradation products;
- Mechanical:
  - Friction;
  - Shock;
  - Impact;

- Direct source:
  - Naked flame.

A number of mechanisms were readily eliminated as they were inconsistent with witness statements and evidence from the incident scene. There is no evidence to suggest that contraband[1] was present in the building; therefore direct sources of ignition and electromagnetic energy can be eliminated as potential causes. Witness reports, supported by photographs from the scene, are consistent with the fire starting in the polyethylene bin of MEK solvent shortly after a quantity of dry NC was added. Calculations have shown that the flammable zone of MEK vapour would only extend to a few centimetres from the liquid surface, which is consistent with moderate volatility and a boiling point at 80 °C. This strongly suggests the source of ignition was localised in the bin, effectively ruling out a vapour explosion due to a distant spark from an external current source such as a fault in electrical equipment.

Mechanical energy was also ruled out on account of the following considerations. Initiation of the NC by shock or impact requires hard surfaces which were not present. Friction from operator handling was considered another plausible mechanism, but as the ignition temperature of NC is around 200 °C, reasonably rough treatment would be needed. In addition, such an ignition would be expected to occur instantly and this is inconsistent with the witness statements.

More detailed studies were undertaken on chemical reaction and electrostatic discharge as remaining potential causes, which are discussed in Sections 8.1.1 and 8.1.2 respectively.

8.1.1 Chemical Reaction

Chemical reaction of materials present in the lacquer process, leading to ignition via heating or destabilisation of the ingredients, could potentially occur by one or more of the following means:

- Contamination or age related degradation during manufacture, storage or use;
- Incorrect supply of ingredients or labelling of storage vessels;
- Use of incorrect solvent;
- Cross contamination between process equipment; and
- Introduction of contaminants through incorrect cleaning of process equipment and contaminated PPE.

A number of possible incompatibilities with MEK were identified that could lead to the release of sufficient energy to cause ignition, and organic peroxides were of particular concern. Three solvent samples were taken for analysis; one sample was taken from a nominally empty drum, and two further samples were taken from a full drum (one from flushing through the dispensing pump, and one directly from the drum).

[1] Contraband is a term used in explosives areas to describe banned items such as lighters, matches, electrical devices and radio transmitters.

The identities of the solvents in the two drums were confirmed to be MEK, by using a range of spectroscopic and thermal analysis techniques, and by subsequent comparison of the results against known samples and literature data. There was evidence of slightly elevated water content in the MEK from the near-empty drum, which is consistent with the length of time since it had been first opened. No significant impurities were observed in the MEK from either drum. A specific test for peroxides was carried out and showed that no measurable concentration of hydrogen peroxide, peracetic acid or organic/inorganic hydroperoxides was present. These results indicate that chemical contamination or degradation of the MEK was not a credible contributory factor to, or source of, ignition.

Another possible source of contaminants identified was the IPA used to wet the NC whilst in storage. Although the IPA should be removed during the drying process, any contaminants present could remain deposited on the surface fibres of the NC. Alternatively, if the NC was inadequately dried, the IPA could lead to the formation of peroxides or interact with MEK. As the NC was dried for 49 hours it is considered that the NC would be sufficiently dry.

The presence of IPA was confirmed in both wet samples, and there was no evidence of gross contamination by organic species. Using thermal techniques it was confirmed that decomposition onset and peak temperatures were consistent with historical data for samples of the chilled NC, as were the decomposition energies. The method of drying (vacuum or heating) had no effect on the thermal stability of the samples. Trace amounts of IPA were identified in the samples dried at 80 °C for 49 hours, but no loss of volatile materials was observed for these samples using thermal techniques. Results of the chemical analysis of NC and IPA suggest that the material involved in the incident is indistinguishable from that used in previous batches of lacquer preparation. Chemical contamination of the NC or IPA is not considered to be a credible source of ignition.

NC is known to be incompatible with strongly alkaline or strongly acidic materials or oxidising agents, and contamination of the lacquer mixture by any of these substances could have resulted in rapid decomposition and ignition of the NC or MEK vapour. Other than NC or MEK, the only other chemicals known to be in the building at the time of the incident were associated with components of the explosive moulding powder and are demonstrated to be compatible with the NC. There is a possibility that traces of oil from process equipment could have contaminated the NC sample during the drying process, although the oil is likely to be chemically inert. Process equipment lubricants are routinely tested for compatibility with explosives and are unlikely to react with the process ingredients with sufficient energy release to account for the occurrence of the fire. There is also a possibility that the NC drying process could have caused some self-heating leading to the generation of chemical substances (e.g. nitric acid or peroxides) that are incompatible with MEK. Investigating this mechanism would require tests with larger quantities of material. This work should form part of the recommended process review (Recommendation 1).

8.1.2 Electrostatic Discharge

The presence of insulating materials creates the possibility for electrostatic charge accumulation. If this is coupled with feasible electrostatic charging mechanisms and discharge pathways then an energy source is created.

Insulators present in the processing area included polyethylene bins and bags for the NC, operator gloves and PTFE coated coveralls. Dry NC itself is a good insulator with a very high specific surface area (>5 m^2/g). The bin and the NC are the only items of direct interest given the reported starting location of the fire. Some charging of the bin material is possible from cleaning or filling with solvent, but calculations show that a much larger charge can build on the NC due to its large surface area. The following process factors will contribute to the build up of charge on the NC.

- Evaporation of the IPA wetting agent when drying the NC;
- Handling and weighing of the dry NC;
- Use of normal polythene bags for storage and weighing;
- Use of insulating gloves and PTFE coated over suits; and
- Tearing, separation and breaking up the NC into small pieces.

Environmental factors can have a significant bearing on the amount of charge build up. Low relative humidity in particular is known to increase the risk of electrostatic discharge. Humidity levels in the building were not measured or controlled. It is estimated that 100 g quantities of NC could accumulate more than one Joule of electrostatic energy.

Potential discharge mechanisms identified which could cause ignition of the MEK vapour or NC are:

- Spark from the introduction of a conducting object;
- Discharge between the fibres of NC; and
- Discharge between the NC and a localised charged area of the mixing bin.

There is no evidence to support the presence of a conducting object (e.g. metal stirrer).

Once charged the NC will undergo numerous small discharges as it is manipulated, placed on the surface of the MEK within the bin, and as it settles in the liquid. The energy in these discharges will have a broad distribution with a maximum energy estimated to be around 1 mJ with the majority at lower energies. The higher energy discharges are thus above the threshold for MEK ignition, but considerably below the threshold for NC ignition.

In order for ignition to occur, a number of conditions need to be satisfied; these include:

- Presence of a flammable MEK vapour/air mixture;
- A sufficiently large piece of electrostatically charged NC must remain on the MEK liquid surface for sufficient duration;

- A discharge of sufficient energy to ignite the MEK vapour; and
- Co-location of the localised discharge and the flammable MEK/air region.

It is concluded that these conditions were likely to have been present on the day.

8.1.3 Evaluation

The technical investigation team identified and evaluated possible sources of energy that could lead to ignition of the materials used in the lacquer preparation process. Mechanical, electromagnetic and electrical equipment sources were readily ruled out as inconsistent with witness statements and observations from the scene. Chemical analysis of the MEK has shown that it meets the manufacturer's specification and contains no significant impurities. Chemical analysis of the NC has shown that it is consistent with previous samples of NC and does not contain any unexpected contamination or degradation products. This effectively rules out chemical reaction as the source of energy for ignition unless there is a subtle mechanism operating when larger quantities of material are dried. The recommended process review should consider what tests are necessary to ensure scale up is fully understood.

Several electrical charge build up mechanisms were identified leading to accumulation of charge on the dry NC. This included the drying of NC, the use of polythene bags and the handling and tearing up of the material during addition to the MEK. Calculations have shown that a significant amount of electrical charge may be accumulated on and discharged from the NC. These charges can exceed the minimum ignition energy threshold of MEK vapour. The low minimum ignition energy of MEK compared to that of NC suggests that it is more likely that the MEK vapour was ignited by electrostatic discharge rather than the NC.

It is concluded that the most likely direct cause of ignition was electrostatic discharge within the NC as it settled through the flammable zone of the MEK vapour in the lacquer preparation bin. This is consistent with witness reports and observations from the scene. Direct electrostatic ignition of NC and electrostatic discharge from the polyethylene container cannot be ruled out, but these are considered much less likely. Once one material was ignited propagation to the other would have occurred immediately. This may have included the rapid combustion of the nearby bag of approximately 300 g residual dry NC accounting for the reported flash and minor burns suffered by one operator.

The lacquer preparation process had been completed successfully approximately 2000 times before without a fire occurring. No significant process differences were found to be present on the day of the fire. The explanation for why a fire occurred on this particular occasion probably lies in the inherent variability of NC at the microscopic level, the small fraction of discharges having energy greater than the MEK ignition threshold, and the need for the discharge to occur in the narrow zone of the flammable layer.

Recommendation 1: No further lacquer preparation should take place until a full review of the process has been carried out with the objective of either eliminating the hazards or reducing to ALARP the risk of harm and fire through engineered controls.

8.2 Management System

The method by which lacquer preparation is to be carried out is defined in the process Operating Instructions. The safety requirements contained within the Operating Instruction should be established by carrying out hazard analyses and risk assessments, with the outcome from the risk assessment used to determine the required engineering and procedural control measures. The requirement to carry out such assessments comes from various Company Safety Instructions (CSIs) which in turn interpret requirements from UK legislation in the area of explosives and solvent safety. This section discusses the various assessments carried out for , their adequacy and a discussion of the effectiveness of the overall safety management system associated with the process of lacquer preparation.

Figure 1. below shows the relationship between the management system documentation and requirements which are relevant to explosives manufacture.

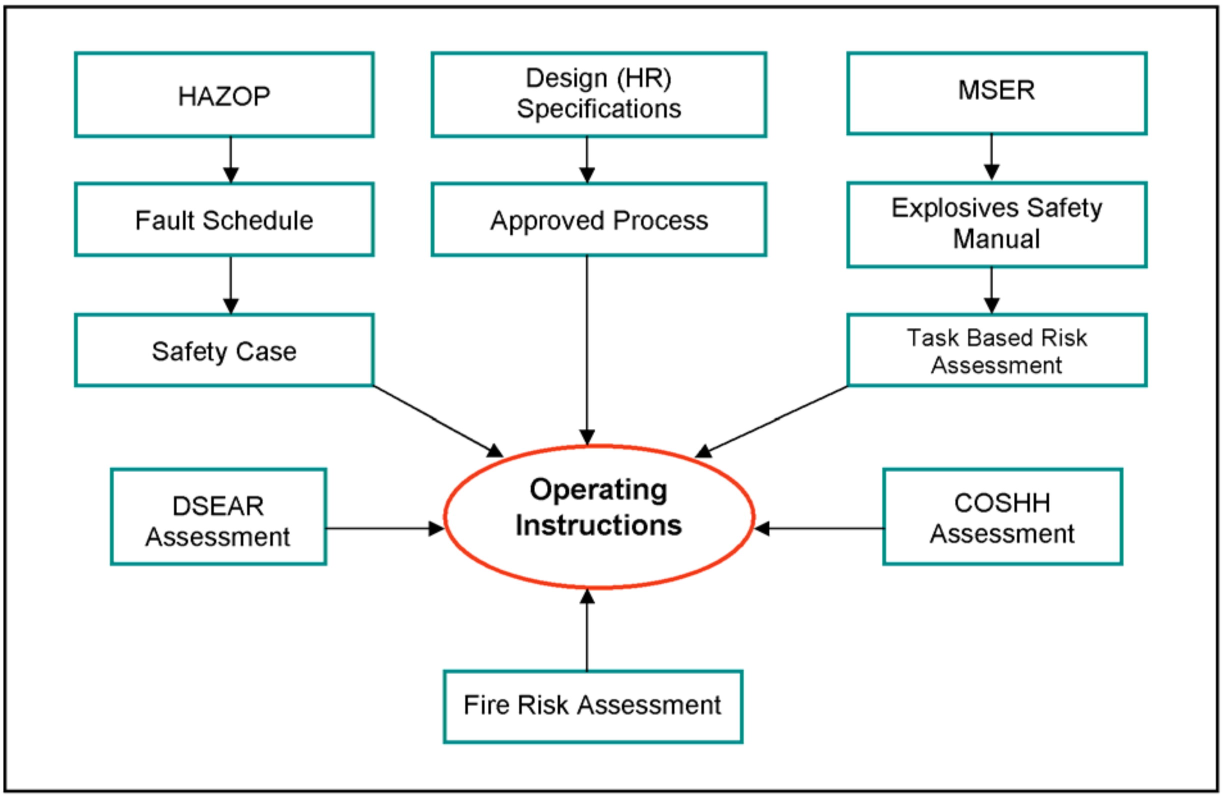

Figure 1. Management System Hierarchy

8.2.1 <u>Legislative Requirements & Company Documentation</u>

This section examines the legislative requirements relevant to the operations conducted in , and discusses how they are implemented both in Company documentation and within .

8.2.1.1 Dangerous Substances & Explosives Atmosphere Regulations (DSEAR)

Where a dangerous substance or explosive atmosphere may be present in the workplace, DSEAR requires that the employer shall make a suitable and sufficient assessment of the risks. The assessment is required to identify all potential sources of ignition and the mitigation in place to prevent ignition from these sources.

These requirements have been addressed across a number of documents within the Company Management System. Whilst the totality of the Company documentation enables compliance to be demonstrated with the requirements of DSEAR, these remain dispersed across a number of documents, increasing the potential for failing to implement all of the requirements applicable to a specific process or facility.

The DSEAR risk assessment for correctly identifies that a flammable atmosphere can be generated with the MEK used in the lacquer preparation process. However, it has been shown this is likely to be present in a thin layer between the liquid surface and the top of the lacquer preparation bin. The assessment fails to cover the potential for an explosive atmosphere with regard to the generation of fibres or dust from the NC. The investigation has noted that improved Company guidance could be provided on the hazards and assessments associated with dusts. Furthermore, the assessment neither identifies all of the potential sources of ignition, nor for those ignition sources identified, the mitigation to prevent them for occurring.

In order to satisfy the mitigation requirements of DSEAR, the equivalent of a conducting regime (equivalent to second degree precaution in the Manufacture and Storage of Explosives Regulations) would have been appropriate for work with a solvent of high flammability such as MEK, and a flammable dust such as that produced from the dry NC. Whilst some measures were in place to earth people in the building (such as conducting flooring and use of conducting shoes), the conducting regime should have placed limits on plastics and other materials potentially capable of generating electrostatic charges. It also should have required measures to provide earthing of people, clothing and equipment so that any electrostatic charges would be dissipated effectively. As discussed in Sections 6.2 and 8.1.2, a range of plastics were in use in during the lacquer preparation and the operators were wearing insulating gloves; therefore, a fully conducting regime was not in operation.

8.2.1.2 Manufacture & Storage of Explosives Regulations (MSER)

Where explosives are being manufactured or stored in a workplace, MSER requires that the employer shall make a suitable and sufficient assessment of the risks. Part of the assessment is required to identify the ignition energy of the explosives being manufactured, stored or processed and then ensure the correct prescribed electrostatic precautions are in place to prevent potential sources of ignition. These requirements are fully captured in the Company Explosive Safety Manual.

Under MSER, the Company is required to have Explosives Licences in place and a copy of the Building Schedule on display for all explosives facilities. The Explosives Licences are issued by the Health and Safety Executive (HSE). For AWE the HSE has agreed that Explosives Safety Orders (XSO) are to be used to set limits on the quantity of explosives permitted in each explosive building, within the requirements of the Licence. In the restrictions when mixing explosive materials are 150 kg of explosives and an additional limit of 80 litres of solvent. The limit on solvent is in place to allow for any potential effect the solvent may have in relation to an initiation of the explosives when the solvent and the explosives are mixed together as a slurry.

The investigation has noted an issue with the clarity of the wording of the XSO for as to how the explosive limits apply when mixing. The problem arises as the mix progresses, as at some point before the mix is finished, the ingredients put into the pan (not all of which are explosive) become 150 kg of explosive moulding powder. In order to comply it is necessary to plan for this and to ensure that before the required ingredients are added to the pan, all other explosives are removed from the building. It has been established that some of the explosives within the building were not required for the mixing operation and should have been removed prior to commencement of mixing. Therefore, at some point on the 3rd August during the explosives mixing process the quantity of explosives in the building exceeded the XSO limit, although the Explosives Site Licence was not breached. Once the mixing process is complete (the state of which is open to interpretation) the limit reverts to 200 kg of explosives.

On the 3rd August the operators brought additional solvent into the building for the preparation of the second batch of lacquer, whilst solvent may still have been present in the mixing pan. Although the additional solvent could be considered as not directly part of the explosives slurry mixing process, it was not good practice to bring it into the room whilst carrying out the mixing process and highlights the need for the XSO to be clear on what is allowed. It should also be noted that the lacquer preparation task was not included in the facility plan of work for that day and therefore had not been authorised by the Work Control Centre (WCC).

It is apparent that there has been some confusion over the classification of NC by the Company. Both the Operating Instruction and Design Specification 1843 state that the dry NC is an explosive. The UK explosives industry uses NC with > 12.6% N; this may have led to some confusion when interpreting the requirements. However, if the dry NC was believed to be explosive there is no evidence, within the risk assessments or an explosive hazards data sheet that, it was assessed as such under MSER.

8.2.2 Hazard Identification & Risk Analyses

8.2.2.1 HAZOP Study & Safety Case

A series of HAZOPs were carried out in support of the creation of the first Safety Case for explosives at AWE. A HAZOP report for HE Development and Manufacture of NC Lacquer was produced in March 1996, and covers the specific process being carried out at the time of the incident. The report lists a number of ways in which NC and MEK can be ignited with associated ‘safeguards’ to prevent ignition from occurring. The postulated causes of ignition are a good match to those proposed by the technical investigation team (Section 8.1) with one notable exception, which is the likelihood of static build up on the NC itself which is not covered in the report. The corresponding safeguards are also listed including the standard management controls such as providing training, Operating Instructions and supervision. The key features of a conducting regime to prevent static build up and discharge are also listed, but not in enough detail to judge whether the current arrangements in are different to those assumed.

The Safety Case was completed in 1999 and remains extant today following an update in 2001 to include the explosive machining operations. The preparation of the lacquer process does not feature in the Fault Schedule within the Safety Case with the result that it was not considered further. Even if the original HAZOP outputs had been carried through in full to the main Fault Schedule, it is unlikely that the protection measures would have been any different from those on the plant today. There is a paragraph in the Safety Case that mentions a lacquer process instruction, which refers out to some generic protection measures elsewhere in the Safety Case for the use of solvents. These protection measures are limited to the use of conducting overshoes, LEV and storage of solvent drums exterior to the building.

8.2.2.2 <u>Risk Assessments</u>

In addition to the DSEAR risk assessment, other risk assessments produced and in place for the facility were:

- Fire Risk Assessment;
- Task Based Risk Assessment;
- Building Risk Assessment; and
- COSHH Assessment.

Both the Fire Risk Assessment and the Task Based Risk Assessment failed to fully identify the required control measures to mitigate the hazards and associated risks from the process materials (MEK and NC).

The Building Risk Assessment is in accordance with the requirements of the Explosives Safety Manual and identifies the potential static hazard and measures in place such as the building earthing system.

The COSHH assessment identified the need for PPE and RPE; however, there is no separate PPE/RPE assessment in place for the lacquer process. There is not enough detail in the COSHH assessment on the PPE/RPE required; it also makes no reference to shoes or footwear.

The investigation also determined there was some conflict in the output of the risk assessments and the identified protection measures; this is considered to be due to the assessments being carried out in isolation of one another. For example, the coveralls and nitryl gloves worn by the operators compromised the conducting regime operated in the building.

8.2.3 <u>Evaluation</u>

At first sight each of the required components of a Safety Management System (SMS) was in place to meet legislative requirements and to inform the design and safe operation of the process. However, the quality of required documents and outputs of the SMS varies. In addition, the connections between documents in the SMS are not always adequately made. For example, the Fire Risk Assessment and the DSEAR assessment do not seem to have taken each other into account. The primary issue with these assessments is that the properties of NC were not well understood, and consequently the hazards from NC and electrostatic discharge were not fed into the various risk assessments for the lacquer preparation process. Without a comprehensive understanding of the hazards, subsequent risk assessments are likely to be deficient.

Although the Company arrangements for complying with MSER are in place, the use and application of Explosive Safety Orders is complex and has led to confusion in their implementation.

Overall, weaknesses in the SMS have reduced the barriers to ignition in and increased the potential consequences of a fire.

Recommendation 2: Ensure that all buildings where explosives are managed or stored are operated in accordance with Explosive Safety Orders (XSOs) which are clear, unambiguous and compliant with the Explosive Licence.

Recommendation 3: Reassess all non-nuclear high hazard processes confirming that hazards have been correctly identified, and where they cannot be eliminated, suitable control measures have been fully implemented. Those processes infrequently operated should not restart until this assessment has been made.

8.3 Procedural Controls

Procedural controls are derived from the hazard and risk assessments discussed in section 8.2. The way the operation is carried out is also heavily influenced by the Design Specification and the Design Authority Approved Process (AP), both of which must be complied with to ensure that a quality assured and consistent product is produced. This section considers the consistency between the Design Specification, as the top level requirement, and the Operating Instructions (OI) which implement it. It also examines operator compliance with the Operating Instructions.

8.3.1 <u>Specifications & Instructions for Explosives Manufacture</u>

There are two Design Specifications relating to the manufacture of explosives moulding powder applicable to the lacquer preparation process:

- High Explosives Moulding Powder; and
- Inspection of Nitrocellulose – medium nitrogen, high viscosity.

The moulding powder specification stipulates the ingredients needed for the process, the recipe to be followed and the testing, packaging, inspection and shelf life requirements. This document is described as an 'Under Ministry Control (UMC) Frozen Specification', which means that it is strictly maintained under configuration control. Materials used in the moulding process are required to be certified to specified AWE and national standards, e.g. Inspection of Nitrocellulose for NC and BS 1940, 1964 for MEK.

The recipe is implemented by an Approved Process for the manufacture of HE moulding powder, as approved by the AWE Design and Quality Assurance Authorities. The Approved Process bridges to the Operating Instructions and provides more detail on the process, the specific equipment to be used and special instructions such as use of PPE.

These documents tightly control some aspects of the moulding and lacquer preparation processes, e.g. mixing vessel temperatures, but make no mention of a number of other issues, e.g. exactly how dry NC should be added to the MEK to make the lacquer.

8.3.2 Operating Instructions

The Operating Instruction (OI) for the preparation of nitrocellulose lacquer defines the required procedure to be followed on the 'shop floor' to comply with the Design Specifications and Approved Process. The instruction clearly details how the process should be performed, and highlights specific control measures ("SHALLS") and precautions in red.

From the evidence gathered during the interviews with the operators and supervisor involved in the incident, it appears that the OI was not followed in a number of areas. It is understood that the author of the revision to the OI in 2009 had observed the process. However, no evidence has been found that the OIs were subject to suitable verification and validation involving the process operatives, or subject to walk and talk through sessions to ensure their practicability and accuracy. This operation was planned to be moved to control by a Manufacturing Process Specification in the near future. This may have reduced the apparent importance of the OI in the minds of the operators.

Step 10.7 of the OI specifies that drying of the NC should be undertaken at 90 ± 5ºC, which is in contrast to the reported temperature of approximately 83 ºC achieved.

Step 11.2 of the OI states: *"Lacquer preparation SHALL be carried out within the 60 Gallon pan enclosure with the LEV switched ON"*. This is in contrast to how the lacquer preparation was carried out on the evening of the incident, whereby decanting of the MEK and addition of the NC to the bins took place in the open area next to the enclosure, not within it. The investigation has determined that it was not routine practice to complete this part of the process in the enclosure, and that due to the configuration of the enclosure there would be limited space to be able to do this.

Steps 11.5 – 11.8 specify the sequence of events which follow the NC addition to the MEK. This sequence was not followed as the decision was made to delay mixing of the second batch of lacquer to the following day, rather than mix immediately as was routine practice. Step 2.2 (General Instructions) states: *"All Steps within this Operating Instruction shall be completed sequentially unless otherwise instructed by a suitably authorised supervisor and/or Work Supervisory Officer"*.

Step 11.12 requires lacquer preparation Steps 11.2 – 11.10 to be repeated for each bin of lacquer; however, 3 bins were filled with MEK at the same time rather than being prepared separately.

Furthermore, there is no evidence to confirm wetting of surplus NC with demineralised water, prior to sending it for destruction (as specified in Step 10.14).

Additional discrepancies were noted with the OI:

- The OI does not state how to add the NC to the MEK; interviews with operators of the process suggest that different operators perform this task differently.
- No minimum or maximum drying time is prescribed for the NC.
- A list of PPE that shall be worn for the process is provided (and EN standards quoted), but this is not prescriptive enough to specify exactly what equipment is needed.
- The OI does not specify when to use the PPE.

8.3.3 Document Inconsistencies

A comparison of the requirements in the Design Specifications and Approved Process (as referred to in Section 8.3.1) and process Operating Instructions (as referred to above) has revealed a number of inconsistencies between the sets of documents. Specific examples include:

- The Approved Process (AP) (para. 1.4) states that air hoods and heavy duty butyl rubber gloves (taped to overalls) are to be worn. The Operating Instruction does not reflect this; it is considered likely that the requirement changed following the installation of the enclosure.
- AP para. 3.2 states the NC should be dried at 100 ± 5ºC whereas the Operating Instruction (step 10.7) specifies 90 ± 5ºC.
- AP para 3.4 requires the lacquer to be mixed to achieve 12-15 g/l whereas the HR Specification (para. 9.22) states 18-22 g/l.
- AP para 3.12 requires stirring for a further 90 ± 10minutes whereas the HR Specification (para. 9.3.9) states 110 ± 10 minutes.

The investigation has not been able to confirm that all relevant concessions and production permits were in place to authorise these differences.

8.3.4 Evaluation

Whilst the discrepancies between the Design Specifications, Approved Process and Operating Instructions are unlikely to have directly contributed to the incident, the lack of clarity regarding both the procedural and safety requirements for the process could contribute to an approach that does what seems practical to get the job done, based on an interpretation of custom and practice. Precision and consistency are essential for both quality and safety reasons during such high hazard activities.

Recommendation 4: Review the set of product Design Specifications, Approved Processes and Operating Instructions to ensure they are up to date, consistent and practical to safely implement.

8.4 Engineering & Modification Controls

This section considers the adequacy of engineering controls in place in , and the effect of changes to the process and building as identified through the facility modification control process.

8.4.1 Engineering Controls

has a number of engineered safety features to protect against fire and explosion. Those features relevant to the lacquer preparation process are the conducting floor, the Hazardous Area Personal Test Meter (HAPTM - used to confirm the earthing pathway through personnel) and the LEV system. The conducting floor and HAPTM meter provide part of the regime to mitigate static discharge and ignition of either the MEK vapour or the NC. The building also has lightning protection and earth bonding of all fixed equipment.

The LEV comprises of one fan and an associated power unit connected to three ventilation ducts terminating in extract hoods above the three mixing pans – two in the main room and one in the enclosure. This configuration enables some work to be carried out in the main process area without RPE while the HE moulding powder is being mixed in the enclosure. The LEV is reconfigured to extract over the two small pans when the NC is being dried within them, with the IPA wetting agent evaporating and being extracted to atmosphere. Dampers on the 10 and 5 gallon mixing pan extract need to be closed for the 60 gallon mixing pan enclosure to achieve the required linear flow rate. The drying process is a precursor to the lacquer preparation process and should not take place at the same time as the HE mix is taking place in the 60 gallon pan.

The Operating Instruction requires the lacquer preparation to take place in the 60 gallon pan enclosure with the LEV on. This affords some local extract to remove MEK vapour, although the work is carried out with RPE, so the main benefit is to reduce the build up of a flammable mix of air and MEK during high speed mixing. However, the investigation determined that the MEK was decanted into the lacquer preparation bins in the main process area (as discussed in Section 8.3.2), where there was no ventilation other than air movement caused by flow into the 60 gallon enclosure.

The building systems are on a routine maintenance programme whose periodicity and compliance has been assured by the Maintenance Authority. The LEV is tested annually and has also met the appropriate air flow characteristics.

8.4.2 Facility Modification Control

Modifications that took place in the facility were identified through a review of local change control documents and no major issues were found. The only modification of direct relevance to the lacquer preparation process was a change to the Operating Instructions in 1995, which principally came about due to a change to the NC drying heat source from steam to water. The opportunity was taken at this time to decrease the amount of dry NC stored; incorporate LEV testing into the process instructions; and to reduce the amount of NC transported.

There were further updates to the Operating Instructions for both the Manufacture of HE Moulding Powder and Preparation of Nitrocellulose Lacquer in March and May 2009 respectively. These went through a document review process rather than modification change control.

8.4.3 Evaluation

The engineered protection measures are designed to prevent the generation and build up of static electricity, to provide protection from lightning strikes and ventilation to reduce MEK vapour concentrations. All these systems have appropriate maintenance regimes that have been effectively implemented. However, without a comprehensive understanding of the hazards, particularly NC and MEK, these measures have the potential to provide an inadequate level of protection. For example, polythene bins were used for mixing the lacquer and polythene bags were used for the storage of dried NC, both of which increase the likelihood of static build-up. In addition, the conducting regime was not complete as insulating gloves were worn (as a skin protection measure against MEK).

8.5 Resource & Production Management

8.5.1 Work Tasking & Planning

The August 2010 campaign of manufacture of explosives moulding powder was scheduled in order to test capability. It was also planned to underwrite the use of chilled NC and the change in location of HMX processing by the supplier. There was no key milestone date or timescale to complete the work. However, due to construction work for the sustainment and replacement facility project (and the requirements for the deployment of Non-Explosives Area Support Workers), there was a perceived limited window of opportunity when would be available for the campaign.

On a week to week basis, the team uses a plan to identify what work will be carried out and on which day of the week each process will take place. The plan is agreed with the Work Control Centre (WCC) for B Area to ensure any necessary de-conflictions can be managed and any required support arranged, e.g. a Facility Emergency Controller (FEC) and Ballistic Trauma First Aider. The plan applicable to the week of the incident was for the week ending the 6th August. The lacquer preparation process was not scheduled to take place on the 3rd August, but since the HE mixing process was underway on the evening of the 3rd, as scheduled in the plan, the necessary emergency response and safety support staff were in place.

The investigation revealed that there were differing opinions on the adequacy of resource for the facility and the timeliness of planning, maintenance and other preparatory production activities. At the operations level, the availability of suitably trained and competent resource for the lacquer preparation and moulding powder manufacture processes was expressed as an issue, leading to a number of last minute changes on the day. There was a perceived feeling of pressure on the explosives powder team, despite the absence of any key milestones. This pressure appears to have led to the decision to accelerate work on the second batch of lacquer by mixing NC and MEK on the evening of 3rd August, using available resources, whilst awaiting completion of mixing of the first batch of the HE. A number of staff intended to work up to a 16 hour day, without any provision for shift changes, as was common practice for this activity.

Neither the Operating Instructions nor the Task Based Risk Assessment contains any specific provisions related to carrying out the process outside normal working hours or with extended working. An assessment was made by the WCC on the Silent Hours/Weekend Notification Form regarding the risk level of the operation and required manning levels in terms of emergency response and first aid cover. There is no evidence that a review of the risk assessment was conducted to consider if there was an impact from performing the process out of hours with staff working overtime. Regardless of this, the lacquer preparation was not on the list of planned activities for that day.

8.5.2 Competence & Training

There is a comprehensive competency matrix for the Explosives Operations Team covering: core competencies; mandatory training; and technical and people management competencies, but there is no formal assessment process behind the training of operational staff to establish that these competencies have been met. Operatives are cycled so that the experienced operators take the new operators through a task, which starts with a brief on the Safe System of Work. Most of the operators had some experience in the process, but there was a general lack of understanding of the hazards of handling NC.

Evidence of a process specific development objective set for the operator carrying out the lacquer mixing process was found and shown to be completed. A matrix is also in place for the various operational processes undertaken by the team, although this has not been completed with either expected or achieved levels. No other evidence has been provided to show how an individual's competency has been assessed against the criteria set, and no records or sign off have been provided that show on the job training for the operational processes has been carried out.

8.5.3 Organisational Change

As part of the Company's Transformation Programme, the Assembly and Explosive Operations (AXO) Asset was formed on May 13th 2010, and a number of organisational changes took place that affected personnel associated with this incident. The key changes were the splitting of the Facility Manager role into separate facility and operational roles, with a Production Manager reporting to the new Operations Manager post. As with all changes to the organisation, these changes had been assessed through the Company's management of change process and were deemed to be acceptable.

From the interviews held with facility staff and management, it was evident that a number of individuals were new to this part of the organisation or had had recent changes to their roles and responsibilities. In general there appeared to be a lack of detailed understanding of the current operation of lacquer preparation process and of the control measures specified by the Explosives Safety Order. Furthermore, there was a general lack of understanding of the hazards of handling NC. There was no evidence that any formal induction process or training had been given in support of these new roles, to demonstrate that individuals were familiar with the current, agreed way of carrying out operations before fully taking up their new responsibilities.

8.5.4 <u>Evaluation</u>

A desire to accelerate work in order to ease potential resource difficulties on the following day appears to have been behind the decision of the supervisor to undertake the first steps of lacquer preparation on the evening of 3rd August, despite it not being on the day's plan of work. Taking such decisions without a more formalised assessment and approval is not appropriate, particularly when staff have already worked a 12 hour day.

Those individuals undertaking the process were generally familiar with it, albeit on an infrequent basis. Training appears to have been largely by demonstration from experienced operators rather than by use of approved Operating Instructions and supporting risk assessments. There is a lack of rigour in formally recording the level of training and competence achieved; this may have contributed to an acceptance of historic practices, which in themselves appear to have evolved over time and varied between different operators. There also seems to have been little challenge to the established methods and practices, such as long working hours, so that a range of issues were not identified and given further consideration before operations took place. These issues include: the differences between the Operating Instructions and actual working practices; clarity of compliance with the XSO; adequacy of the conducting regime in the facility; and the lack of knowledge of the hazardous properties of NC.

The restart of operations in B area in 2007 attempted to enhance behaviours and practices in the explosives area, but this appears to have either been only partially successful or standards have begun to slip with time. The May 2010 reorganisation provided another opportunity for those new in post to set standards for staff, and to challenge working practices; however, it is not evident that this had happened by the time of the fire.

Whilst the above issues were not a direct cause of the fire occurring in , they did lead directly to the decision to prepare NC lacquer in parallel with the completion of a batch of HE moulding powder, and the threat of an explosion of the moulding powder and HMX within the building at the time of the incident. Such a threat would not have been present if parallel work on a second batch of lacquer for the HE process had not commenced, and if the unused HMX explosive had been removed.

Recommendation 5: Ensure that a suitable training and competency system is in place and fully implemented for all high hazard non-nuclear operations.

Recommendation 6: Ensure that the formation of operating teams for high hazard batch processes recognises the importance of resource planning, team cohesion and the avoidance of significantly extended working hours.

8.6 Missed Learning Opportunities

This section provides reviews of experience, internal and external to AWE, and considers whether such experience should have been recognised, thereby providing an opportunity to have prevented the fire.

8.6.1 <u>Internal Incidents</u>

A review of Abnormal Events (AEs) occurring over the last 10 years in , and other facilities using comparable processes or materials, identified no similar types of incident. Whilst there have been issues over maintenance of equipment, spills of solvents etc and one incident of a small solvent fire in a different facility, none of these had critical similarities with the incident in question in terms of either the process or specific materials involved.

8.6.2 <u>External Incidents</u>

A review was undertaken to identify any external incidents that have occurred involving the ignition of NC and MEK. Over 160 external incidents were identified but none were found to be of particular similarity to that in . However, a number of incidents had elements that may be of relevance, e.g. spark initiation and stability issues.

Of those incidents reported involving the handling of NC, the most relevant of these stated: '*Whilst nitrocellulose powder was being emptied from a fibre container into a plastic drum, the contents flared up. The accident was probably caused by a static spark igniting the ether vapour. The operative sustained minor burns'.* Available summaries of this incident do not provide full information on key details, such as NC nitrogen content or whether NC was wet or dry.

The HSE and manufacturers of NC have provided guidance on the storage, handling and use of the material, and from these it is clear that the inherent instability of NC requires special measures, particularly in the avoidance of electrostatic discharge. This view is also supported by the findings of the external incident review. Yet it appears that this guidance, applicable to AWE's use of NC, was not known to the relevant parts of the Company.

8.6.3 <u>Audit, Inspection & Review</u>

A review was undertaken of the audit and inspection activities carried out over the past 3 years in ; this included Case for Continued Operations (CfCOs), Acceptance Review (AR) reports, Corporate and local audits, and Local Management Assurance Inspections (LMAIs).

The issues covered by the audits/inspections over the period included explosives moves, licence transition activities and MSER (Regulation 4) compliance. LMAIs were annual, and largely addressed house keeping and maintenance issues. The one assessment activity to look in more detail at the process in the building in question was the CfCO and its associated acceptance review, although it should be noted that none of these assessment activities, or any performed by the HSE inspector, took place while the mixing process was actually being carried out.

Company level audits and inspections did note that there were issues related to demonstrability of competence for certain posts (e.g. Explosives Keeper), and that there was sometimes reliance on expertise outside the business area for explosives safety advice. Local audits appeared to place few actions, and the most recent LMAI (April 2010) identified issues linked to explosive waste accumulation, degradation of paintwork on mixing pans and noted a loose cover on an extract filter.

The acceptance review to the 2009 CfCO specifically addressed the building and its processes. This identified concerns with the completeness of fire risk assessments and the lack of adequate translation of findings from the DSEAR assessment into recommendations and controls. However, the investigation found that these assessments still have deficiencies as outlined in Section 8.2.1.1.

None of these assessments are designed to fundamentally challenge the use of hazardous materials, or in this case specific details of the lacquer process, but are used more to give an overall insight into a facility's safety management arrangements and compliance with the Company's arrangements.

8.6.4 Process Reviews

Work is underway to assess and scope the explosive manufacturing processes that will eventually form part of the facility being delivered by project Scorpius, including those activities carried out in . Scorpius is in the early stages of development where concepts are being tested to properly scope the project. This work includes a preliminary understanding of the hazards and considers how the processes should be performed in the new facility. It is not clear how this information is communicated to allow an assessment of any implications on current operations. It is worth noting that the potential for static charge build up on the dried NC as an ignition source for MEK was not identified.

8.6.5 Evaluation

Whilst this incident is not a repeat event at AWE, there is extensive information available on the specific hazards of NC and solvents in general, and the precautions required for their use. In addition, there is expertise on NC within the Company, but this has focussed on the effects on HE product quality rather than operational safety surrounding the use of process ingredients. This knowledge does not appear to have adequately informed the Safety Management System, Operating Instructions, training requirements or the staff concerned.

Although the facility was subject to a range of inspections and audits, these generally did not cover infrequent, hazardous operations. A greater focus on testing process safety would have provided greater opportunity to identify deficiencies in these operations.

Recommendation 7: Strengthen the arrangements to enable the Company to effectively draw on defence sector, and other external sources of expertise and experience of energetic materials and processes.

Recommendation 8: Establish a process for periodic review of high hazard non-nuclear processes against modern standards.

Recommendation 9: Ensure that audit and inspection programmes adequately test the process safety aspects of high hazard activities, particularly where these are infrequently performed.

9 EMERGENCY RESPONSE

The following sections consider the response to the incident and the lessons to be learned.

9.1 Initial Response & Information

The immediate response was provided by AWE Fire and Rescue Service (FRS). Their initial concern was for the nature and location of potential casualties and they deployed directly to , rather than follow standard practice to go to the Work Control Centre (WCC) where the Facility Emergency Controller was situated and could have briefed them on the casualty and explosives position.

Fire suppression was deployed to the outside of the building but no internal entrance was attempted. The dynamic risk assessment and approach to the building was based on partial information and placed forward personnel and equipment at risk during this early stage prior to an exclusion zone being applied.

The call in of Local Authority emergency services and AWE technical and specialist staff took place quickly and expertise was available to the emergency services and incident commander. No actual fire fighting was conducted by Royal Berkshire Fire and Rescue Service (RBFRS) as resources were deployed in a stand by or suppression mode, which is standard practice in a fire involving explosive buildings.

9.2 Awareness of Emergency Plans & Preparedness

Information about the explosives in was available in the 'out of hours' notification prior to operations commencing, but was not known to the initial response team. This shortage of immediate information (within approximately the first 15 minutes) was exacerbated by a general inadequacy of knowledge of facility emergency plans, safe routes, pre-operation briefing, equipment location and preparation, length of working day, adherence to Standard Operating Procedures and out of normal working hours manning levels. The building control centre was not manned to normal day time manning levels and the Facility Emergency Controller (FEC) was under pressure dealing with all the requests for information until additional assistance arrived. Evacuation of the building by the operatives involved was initially to the Emergency Assembly Building and then, after initial first aid assessment, via a safe route selected by the individuals. Whilst this was the safest and most sensible route it was not pre-planned.

9.3 Cordon Implementation

On confirmation of the fire and of the explosive contents of the building an initial cordon (exclusion zone) of 400 m was established. Implementation of this was conducted by Ministry of Defence Police (MDP) in agreement with Thames Valley Police. The initial 400 m zone was based on police advice and followed standard procedures for security related incidents. In practice the Facility Emergency Response Plan (FERP) and Home Office guidance requires an exclusion zone of 600m. The 400 m zone was increased to 600 m on arrival of AWE specialist staff and the RBFRS.

The RBFRS assumed incident control on arrival in accordance with standard practice with AWE FRS in support. The 600 m exclusion zone extended beyond AWE site boundaries and resulted in the evacuation of local residents to AWE facilities and some local road closures. This evacuation was notified to the Local Authority but the Local Authority Off Site Response plan was not initiated. This plan is derived from Radiation Emergency Preparedness and Public Information Regulations (REPPIR) requirements and although there is some reference to non-radiological hazards, the plan is largely directed towards radiological incidents. There is no requirement for an AWE off-site plan under Control of Major Accident Hazards (COMAH) regulations. By default the standard exclusion zone of 600 m extends beyond AWE site boundaries, albeit the siting of the AWE explosive area and restriction of surrounding development means that only a small civil population is ever likely to be affected.

There was some brief confusion and counter-order on the eventual lifting of the exclusion zone. In part this was due to a communication issue between the Site Control Centre (SCC) and Incident Control Point, and possibly some misunderstanding as to the respective roles of the Incident Commander and the site Emergency Manager. As this is a considered step in a stable situation, a more formal written process would assist in avoiding such confusion in future.

9.4 Risk Assessment Records

Although substantial Local Authority resource was deployed, primarily RBFRS, no actual fire fighting was involved. There was a good flow of specialist information to the Incident Commander to enable risk assessments to be conducted. Additional specialist equipment (robotics, thermal cameras and helicopters) was summoned to assist in risk assessment and confirmation of hot spots. The deployment of the robot and other resources required activity by emergency personnel within the exclusion zone. Whilst these events were logged, the underpinning risk assessment and the decision to proceed do not appear to have been recorded. Consideration should be given as to whether such actions would benefit from more detailed documentation.

Environmental sampling was conducted during the night to check for any pollution, particularly asbestos; all results indicated no elevated levels of contaminants. Consideration was also given to water run off effects. Hazmat officers were deployed and the Environment Agency (EA) informed of activities.

9.5 Communications

Communications throughout the incident generally worked well; however, a number of areas require more radios and there were some interoperability issues with the system used by the police. Notification improvements could also be made, particularly to external stakeholders who have a need for information but may not need to provide immediate support.

The initial entrance of Local Authority support resources into AWE was rapid and experienced no security delays. Later replacements experienced some delay possibly due to communications between the SCC and the AWE Main Gate. The delay may also have been due to a wait for more Thermo Luminescent Dosimeters (TLD) for fire crews. In practice there was no need for TLD but standing practice required their issue. The delay did not critically affect response effectiveness to this event.

Although the Local Authority had been informed, there was a delay in subsequent communication of information to other interested parties including the Health Protection Agency (HPA) and EA. This appears to have been in part due to subjective judgement of whether they needed to know, as there was no apparent requirement for their services in the event.

Some of the internal pre-operation notification communications and location of keys within AWE may be overly complex and might be simplified to better aid knowledge and briefing.

The AWE Communications Cell was deployed to the SCC and provided effective internal and external communications. The former helped particularly during the smooth entry arrangements for the next working day. Some external disruption was caused due to the exclusion zone but this was minimal. There was little immediate press interest but press office briefings were arranged and standard press communications established.

9.6 Evaluation

The challenges met in a real event provide a test of emergency arrangements that may not be achieved in an exercise. Although the overall outcome of the emergency response was satisfactory there were a number of learning points. The key ones are listed below, but these and other more minor points should be used to drive improvements via a systematic implementation programme.

- The Local Authority Off Site Response Plan, based on REPPIR requirements, is the responsibility of the Local Authority. Expansion of the plan to provide more detail on non-radiological events should be considered.
- Most events of a similar nature at AWE will be of public interest. The deployment of a Local Authority Liaison Officer to AWE for a significant non-nuclear event would assist external communication, briefing and clarify potential action required by external stakeholders.

- The level of awareness and preparedness within AWE for potential emergencies arising from operations at AWE should be reviewed, particularly in the context of out-of-hours working.
- The requirement for formal written orders demonstrating the risk assessment and rationale for key decisions also should be reviewed.
- The information requirements and communication means for all stakeholders should be reviewed with the aim of simplifying, rationalising, standardising and prioritising communication. A requirement for formal written orders demonstrating the risk assessment and rationale for key decisions should also be considered.
- There is a need to ensure that rehearsed procedures are followed in the real events.

Recommendation 10: Provide advice on the required level of awareness and preparedness by AWE for potential emergencies arising during out of hours working, and build into the emergency exercise programme, reinforcing the need to follow designed arrangements.

Recommendation 11: Conduct a joint review with the Local Authority to identify necessary changes to plans for responding off site during non-radiological events. This should include communications in general in a non-nuclear incident.

10 CONCLUSIONS & RECOMMENDATIONS

This section summarises the causes of the fire, and other observations on operations in the affected building and the emergency response.

10.1 Direct Cause of the Fire

The fire in came about during the preparation of a lacquer made by adding dry NC to MEK. It has been concluded that the most probable cause of the fire was from the MEK igniting due to electrostatic discharge, probably taking place within the NC, although it will remain uncertain as to whether the first ignition was of the NC or the MEK. There is also a possibility that the NC drying process could have caused some self-heating leading to the generation of chemical substances that are incompatible with MEK. Clarity on this detail is not critical to why the fire occurred or how similar events can be prevented. Once the MEK had ignited, some of the other combustible materials in the building acted as fuel to maintain the fire; high explosives within the building were not significantly affected by the fire.

The occurrence of a fire on this particular occasion is considered to have been due to an alignment of a number of process variables. As such, a fire could have occurred during the preparation of any lacquer batch. On this occasion, the variability in properties of NC, the build up of electrostatic charge and the distribution of MEK vapour/air concentration in the preparation bin came together to allow initiation and propagation.

10.2 Root Causes of the Fire

The most effective barrier to ignition in the lacquer preparation would have been a process design and implementation that recognised the nature of the materials in use, the variability in properties and conditions, and eliminated or minimised the associated risks. The failure to avoid the fire is concluded to be due to the following root cause.

10.2.1 Knowledge of Process Materials

There was insufficient awareness of the properties and hazards of process materials. This included a lack of in-house knowledge of NC and appreciation of the relevance of the low ignition energy of MEK, yet during the investigation guidance and practical experience was relatively easily obtained from the chemical industry, the HSE and defence sector sources.

These shortcomings led to insufficient attention to lacquer preparation and related electrostatic discharge issues in the hazard identification and risk assessment. The consideration of explosives safety issues had led to a building with significant and relevant engineering controls (e.g. a conducting floor, lightning protection) but these were compromised during lacquer preparation by the extensive use of insulating materials, such as polythene bins and nitrile gloves, which could allow electrostatic charges to build up.

10.3 Other Observations

The investigation also made a number of other observations which, whilst not directly impacting on the fire, require management attention.

10.3.1 Building Operations

Although the investigation has found that the direct causes of the fire could have happened at any time, the event was of particular impact because of the presence of high explosives in the building. This was due to the decision to prepare a batch of lacquer while an earlier batch of high explosive was being mixed in the adjacent enclosure, and with some unused high explosive ingredients of that batch remaining in the building. The lacquer work was not scheduled but seems to have resulted from a well meaning desire to move the work along while there were operators available. Given the long hours already worked that day any such decisions are increasingly likely to be ill-judged. In addition, there were significant non-compliances with Operating Instructions, Explosives Safety Orders, and planned work schedules which further weakened the barriers to an event involving explosives.

10.3.2 Adequacy of Process Reviews

There was insufficient challenge to existing practices in the lacquer preparation process. Operators were trained by observing and reproducing the process, as demonstrated by more experienced colleagues. This contrasts with an approach of using validated, practical Operating Instructions where the process of validation itself would highlight difficulties with the process as designed. There is also an assumption that processes are 'frozen' and cannot be amended without expensive requalification. Yet in practice, the training method probably allows an unconscious and uncontrolled evolution of the way that work is performed, adding additional process variability. Inspections, audits and organisational changes all provided opportunities for challenge, but for a hazardous operation infrequently carried out these appear to have focussed on general safety management arrangements rather than specific process safety aspects.

10.4 The Emergency Response

Overall a satisfactory outcome of the emergency response was achieved in that there was no harm to incident responders, staff or public. Nevertheless, the incident tested the emergency response arrangements in a manner difficult to achieve in an exercise and some shortcomings were apparent. Necessary improvements to arrangements have been itemised in Section 9.6.

10.4 Recommendations

Recommendation 1: No further lacquer preparation should take place until a full review of the process has been carried out with the objective of either eliminating the hazards or reducing to ALARP the risk of harm and fire through engineered controls.

Recommendation 2: Ensure that all buildings where explosives are managed or stored are operated in accordance with Explosive Safety Orders (XSOs) which are clear, unambiguous and compliant with the Explosive Licence.

Recommendation 3: Reassess all non-nuclear high hazard processes confirming that hazards have been correctly identified, and where they cannot be eliminated, suitable control measures have been fully implemented. Those processes infrequently operated should not restart until this assessment has been made.

Recommendation 4: Review the set of product Design Specifications, Approved Processes and Operating Instructions to ensure they are up to date, consistent and practical to safely implement.

Recommendation 5: Ensure that a suitable training and competency system is in place and fully implemented for all high hazard non-nuclear operations.

Recommendation 6: Ensure that the formation of operating teams for high hazard batch processes recognises the importance of resource planning, team cohesion and the avoidance of significantly extended working hours.

Recommendation 7: Strengthen the arrangements to enable the Company to effectively draw on defence sector, and other external sources of expertise and experience of energetic materials and processes.

Recommendation 8: Establish a process for periodic review of high hazard non-nuclear processes against modern standards.

Recommendation 9: Ensure that audit and inspection programmes adequately test the process safety aspects of high hazard activities, particularly where these are infrequently performed.

Recommendation 10: Provide advice on the required level of awareness and preparedness by AWE for potential emergencies arising during out of hours working, and build into the emergency exercise programme, reinforcing the need to follow designed arrangements.

Recommendation 11: Conduct a joint review with the Local Authority to identify necessary changes to plans for responding off site during non-radiological events. This should include communications in general in a non-nuclear incident.

ANNEX A – TERMS OF REFERENCE

Terms of Reference for the Independent Investigation into the Fire within Building on the 3rd August 2010

Investigation Sponsors

Chief Executive Officer (CEO)
Director Environment, Safety & Health (DESH)

Chair	External NSC Member
Internal Team Members	**Role**
(DESH)	Investigation Team Leader
(DESH)	Internal Regulation
Explosives Safety Lead (DESH)	Explosives Safety Authority
Technical Authority Explosives (DC)	Explosives
(DI)	Site Control
Project Engineer (DI)	Trade Union Representative
Group Leader Environmental Management (DESH)	Environment & Author
: (DST)	Technical Investigation Lead

Purpose

To conduct an independent investigation into the fire within building on the 3rd August 2010, and submit a report of the findings and recommendations to the CEO.

Investigation Aims

- To determine the root causes of the incident.
- To review the adequacy of the engineering and management system controls in place for operations within the facility.
- To determine the appropriateness of the risk assessments and method statements for the tasks associated with the incident.
- To consider similar incidents that have occurred both internally and externally.
- To review the methodologies for mixes of similar solvent/compound combinations.
- To review the effectiveness of the emergency response arrangements and cordon control.
- To consider incompatibility and quality control of materials involved in the process.
- To provide a report to the CEO within 2 weeks of the investigation commencing.

Approach

The investigation team will meet daily to discuss required actions, feedback and progress. Initial actions will include:

- Review of photos from the incident scene
- Interview of individuals and witnesses involved in the incident
- Interview of incident responders
- Review risks assessments, operational instructions
- Take advice from external experts as appropriate