Applying Systematic Risk Management Protocol to the Design of a Modern Propellant Manufacturing Plant in Australia

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KEYWORDS
risk management, in-process characterization, classification, risk analysis techniques, key parameters, safety by design

ABSTRACT
The proper application of Risk Management Principles and explosives test data were essential to ensure safe operations at the Mulwala Propellant Plant in Australia. This paper begins with a brief overview of the risk management principles applied from design to commissioning of the Mulwala Redevelopment Project (MRP). It then provides examples of how risk analysis coupled with test data were utilized to identify, evaluate and address potential explosive safety issues.

Each example will illustrate:
1. The explosive safety issues
2. How the issue was identified
3. What analysis techniques were used to define and bound the issue
4. How the proper tests and test parameters were selected based on the risk assessment
5. The test results
6. How the test results were applied to properly address the potential explosive issue.

Systematic risk assessment leads to specifying and performing the explosives tests necessary to ensure safe explosives operations in the various conditions and configurations found in a manufacturing process.

INTRODUCTION

The Mulwala Redevelopment project was a contract with the Australian Department of Defence to design, construct, commission, and qualify a 530 tonnes per year single-base propellant process plant. The site to be upgraded was a munitions factory built in the 1940's to support World War II. The team working on MRP consisted of Lend Lease as the prime, Orbital ATK as the technology provider, and Safety Management Services, Inc. (SMS) as the third-party explosives safety provider. MRP required improved safety, modern and enhanced propellant manufacturing, no possibility of 1.1 events, continued propellant production during construction, and regulatory compliance during and after MRP construction.

To meet these requirements, the MRP team used approaches such as systematic risk assessments, explosives in-process characterization/classification testing, and application of test data to minimize risk. The need for systematic risk assessment and in-process characterization/classification is created by varying process configurations and confinement, variations in energetic material, compositions, physical states, and normal vs. abnormal system insult energies. Accurate classification of explosive substances and articles is essential for all life cycle stages of explosives, which may be different for each operation within each stage. Key in-process parameters include composition, physical state, configuration (confinement or packaging), quantity, conditions (e.g., temperature, pressure, humidity, etc.), and normal and abnormal ignition sources. Tests that incorporate these key parameters are essential to determine proper in-process classification of explosives.

1. Risk Management Principles

The Mulwala Redevelopment project required improved safety, enhanced propellant manufacturing, and elimination of possibility of 1.1 events. The MRP team developed a risk management philosophy to guide their assessment of the project.

"Safety by Design" is an essential component to risk assessment. A common but ineffective approach often used by industry is to develop the concept and design of a process, and once construction begins, proceed with the performance of a hazards analysis to identify potential safety issues and controls. At this point of the process construction, improvements are typically limited to safety features that can be added on to the existing design rather than integrated into the design. This approach is less the optimal for safety feature incorporation and can result in costly process modifications.

A Proactive Systems Approach requires risk management, design hazards analysis, and facility siting options to be considered from the beginning of the concept stage. The hazard and risk assessments are consulted throughout the entire engineering process, from concept, design, construction, start-up, production, all the way to process changes. A safety by design approach minimizes personnel exposure and quantities of hazardous materials while providing safety specifications that or incorporated in to equipment and facility design specifications.

Standards, procedures, and training are also essential to effective risk management. Written standards and procedures incorporating safety by design can be updated and considered throughout all stages of the engineering process. Training personnel and team members in regard to Process Hazards Analysis (PHA) and explosives safety is part of the Proactive Systems Approach as well.

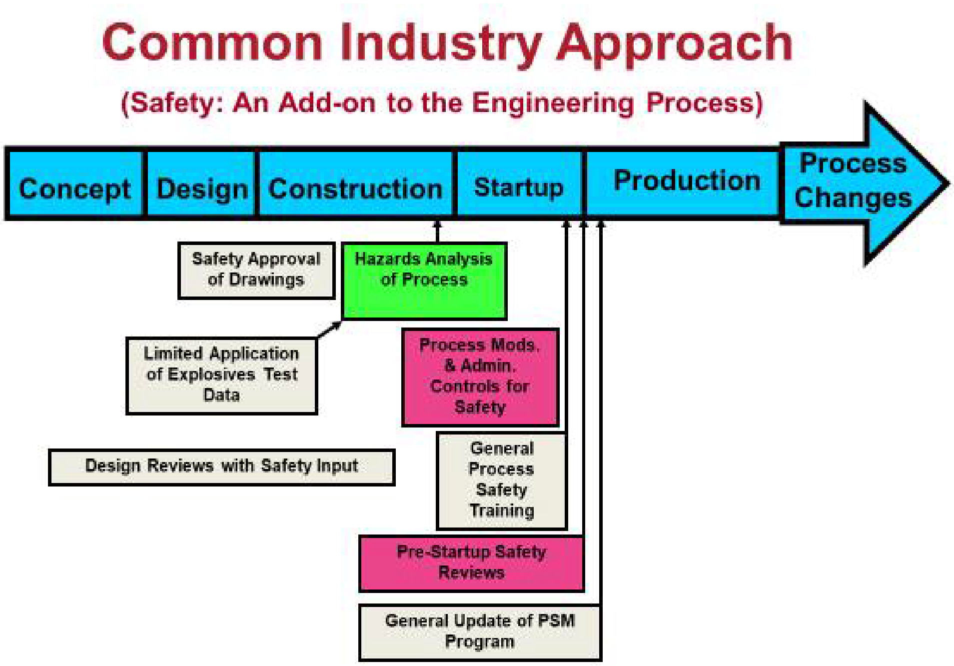

Figure 1. The Common Industry Approach.

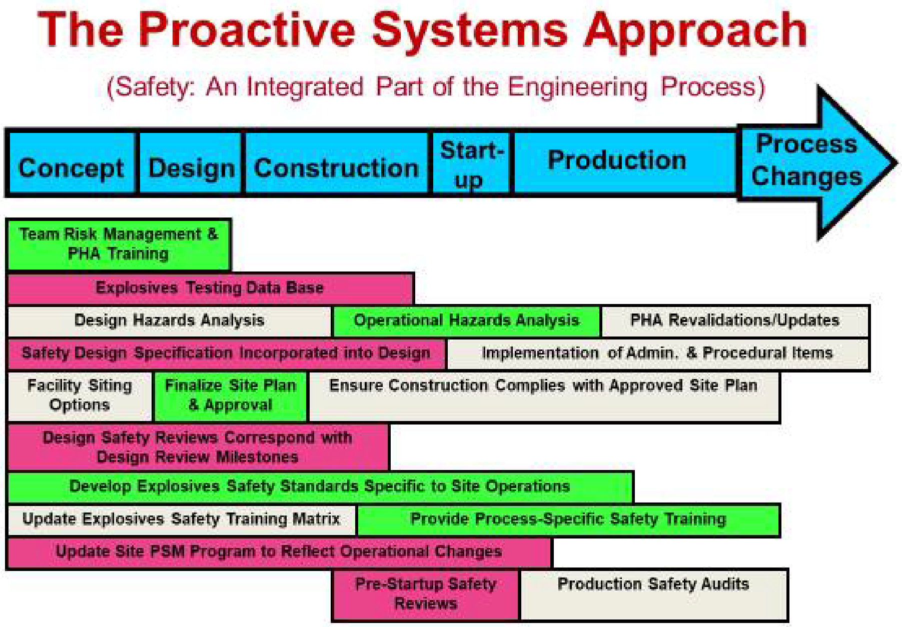

Figure 2. The Proactive Systems Approach.

A successful risk management program includes many elements, with Process Hazards Analysis (PHA) and process safety information being the keystones. Other elements include employee participation, operating procedures, training, contractors, mechanical integrity, pre-startup safety review, incident investigation, hot work permits, emergency plannying and response, mangement of change, compliance audits, and document access/control. All of these elements rest on a foundation of site-specific safety standards, management commitment, and employee accountability.

The need for systematic risk assessment and in-process charactierzation and classification is due to variations in energetic material, process configurations, system insult energies, simple/complex systems, and confinement. There are multiple potential scenarios where the characterization of explosives can vary over its life cycle stages.

Several examples are highlighted below where both risk assessment and in-process classification testing were successfully applied in a proactive systems approach. In-process testing is first briefly reviewed.

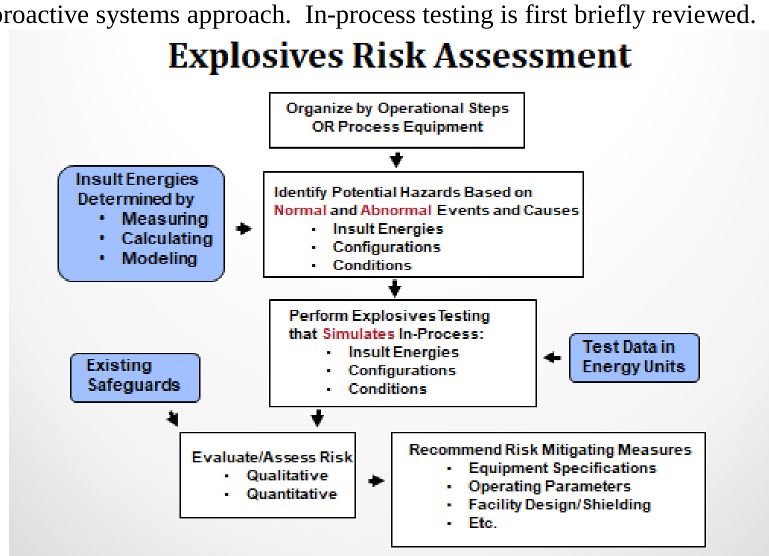

Figure 3. Explosives Risk Assessment Process

2. Application of "In-Process" Characterization and Classification Tests

The Mulwala Redevelopment Project used "in-process" characterization and classification tests to assist in risk assessment. Sensitivity testing included: friction, impact, ESD, and thermal (SBAT) tests. Reactivity testing included: critical height, No. 8 cap sensitivity, NOL card gap, and small-scale burn tests. Subscale, bench-scale, and full-scale simulation tests were also used. Specific information on sensitivity, reactivity, and other testing can be found in ETUG-GS01-15 or at www.etusersgroup.org ("ETUG Standard"; "Test Methods Matrix" 2018).

Process Simulation Modeling was also used for "in-process" characterization and classification tests. Blast modeling on select equipment used the Integrated Violence Model (IVM). The IVM takes into account heat transfer, heat flux, free-space pressure, case yield/fracture, and propellant kinetics methods along with physical fundamentals and experimental data to determine the fragment energy, overpressure, and pressure rate-of-rise of a blast event. Characteristics determined by testing of propellants are inputs to the model.

3. MRP Risk Assessment Examples

In the following section are two examples that illustrate:

1. The explosive safety issue
2. How the issue was identified
3. What analysis techniques were used to define and bound the issue
4. How the proper tests and test parameters were selected based on the risk assessment
5. The test results
6. How the test results were applied to properly address the potential explosive issue.

3.1 Air Dryer

Rotary tray dryers air dry single base gun propellants. The rotary tray dryers were designed and installed by the MRP team ("256xEHSxMP003" 2013). The team applied systematic process hazards analysis, propellant characterization testing, and computer modeling to determine proper design and operating specifications. The Australian Government Department of Defence (ADoD) required that the MRP team demonstrate that a deflagration would be the most significant event.

The rotary tray dryers are used to dry propellants. The safety of the drying operation lies in the dryers being able to safely vent combustion gases from the propellant, should it ignite within the dryer. The dryer design must support a maximum credible event of a burning reaction that can safely be vented.

The potential explosion of the tray dryer should an initiation event occur was identified through hazards analysis of equipment and processes throughout the Mulwala plant. Process Hazards Analyses were performed during all phases of the air dryer design, fabrication, installation, and initial live propellant trials. Any changes to the air dryer or associated processes have been assessed through the Management of Change program which requires an additional hazards assessment. During the PHA process, credible failure scenarios were identified, and recommendations were issued for mitigation.

Performing Process Hazards Analysis (PHA) throughout all phases of design, construction, and startup of the propellant drying process facilitated the Team's philosophy of "safety by design." The PHAs identified the credible normal and abnormal initiation scenarios associated with the air dryers including ancillary support equipment and facilities. Each of these scenarios were addressed by design specifications and/or engineering controls. Additional measures such as training, detailed operation/maintenance procedures, etc. augment these primary controls. Proper PHAs coupled with the integration of design specification and engineering controls into the propellant drying process eliminates or substantially minimizes the risk of an initiation event. Extensive Propellant Characterization Testing was performed on worst case MRP propellants including a Critical Height Testing matrix, Confined Bulk Propellant Testing, and Full-Scale Comparative Testing. The results from all of these tests combined with Computer Modeling (based on worst-case propellant quantities, propellant surface area, and air dryer pressurization rate) confirm that the maximum credible event for the MRP air dryer configuration would be a 1.3 mass fire.

Propellant characterization testing was performed on all MRP propellants to determine their sensitivity to impact, friction, ESD, and thermal stimulus. In addition, the worst-case propellants were tested for reactivity upon ignition from fire or shock. These tests included a #8 cap test, UN Gap test, and critical height testing. Further bulk propellant tests were performed with high confinement, including large-scale reactivity tests not detailed here.

Critical Height testing was also completed for the fastest burning propellants and the outcome applied to the design of the propellant processing equipment including the dryer and propellant feeder, discussed in the next section. The propellant bed depth in the dryer was significantly less than the critical height and thus the risk of explosion from the confinement of the propellant alone was not credible; however, the risk from the confinement of the dryer was evaluated in detail. Sufficient vent panels were installed to prevent an explosive event.

The MRP team used a detailed systematic approach in assessing risk associated with the propellant air dryers. This approach resulted in an air dryer design that eliminated or substantially minimized initiation scenarios through design specifications and engineering controls, provided a configuration that yielded a maximum credible event of a 1.3 mass fire reaction, which was validated by propellant characterization test data, confined bulk propellant testing, full-scale comparative testing, and detailed computer modeling with layers of conservatism.

3.2 Propellant Feeder

Propellant to be packed is delivered to buildings in bulk bags, which are hoisted into position above a hopper, with the bag snouts clamped. A single bulk bag at a time is released into the hopper, from where the propellant is transferred from the bottom of the hopper via a vibratory conveyor to a screener. The MRP team was tasked with characterizing and classifying the worst-case bottom ignition of a Hopper unit fully loaded with propellant ("SMS-2323C-R1, Rev 0" 2014).

The propellant feeder leads into a steel hopper that also is composed of steel parts such as screw, chute, and discharge disks. An ignition can be created from friction and impact stimulus on the steel parts. The hopper needed to be tested as to whether it presented a mass fire (HD 1.3) or mass explosion (HD 1.1) hazard.
The potential explosion was identified through analysis of the feed hopper.

A hazards analysis including a HAZOP analysis and FMEA table was used to identify credible failure scenarios. Through the use of risk assessment tools, key parameters such as composition, physical state, configuration and confinement, and conditions were analyzed. Once these key parameters were evaluated, they were used to narrow down on tests to determine potential hazards.

Sensitivity tests such as the friction and impact tests were used to determine if the steel parts could cause a spark powerful enough to ignite the propellant and cause an explosion. Based on the results of the friction and impact testing, and due to confinement conditions, the steel hopper was changed to a venting canvas hopper as a safety mitigation. Some of the steel parts in the hopper were changed to plastic, which was tested to ensure ESD was within safe limits. Other testing such as the critical height test was used to determine that a maximum fill of a 1:1 ratio of diameter to height along with additional level controls and interlock would be a sufficient safeguard.

It was also tested whether the hopper presents a mass fire (HD 1.3) or mass explosion (HD 1.1) hazard through use of an ignition test, where the propellant is ignited at the junction of the metal hopper and the canvas funnel -- gasses will only be able to initially vent out the bottom of the funnel (vent panels, if present, may not burst or fracture fast enough during the initial burning of the propellant). A full-scale test was completed to determine the outcome. The test incorporates measurement of pressures to determine whether it is a mass fire or mass explosion. High-definition video and high-speed video were recorded during the test, along with blast overpressure.

The criteria used to determine whether a mass explosion occurred includes cratering under the unit, measurement of blast pressure pulses, and observation of a blast using high speed and standard speed video. The ignition test ignited the propellant in the hopper, and ruptured two of the vent panels. However, a majority of the propellant was consumed very quickly, and no fragments or projections were generated.

4. Conclusion

Accurate and systematic risk assessments are key to identifying normal and abnormal process energies and conditions, proper sensitivity and reactivity testing, and testing parameters. In-process sensitivity and reactivity testing coupled with risk assessment provides the proper design specifications for process equipment, control systems, facility siting, manufacturing facilities, barricades, shielding, and other safeguards.

Through the use of systematic risk assessment, in-process characterization and classification testing, and test data, the risk of an explosive event is greatly minimized.

REFERENCES

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