Explosive precursor safety: An application of the Deming Cycle for continuous improvement

General safety regulations need to follow a 'one size fits all' model, which may lead them to inadequately address challenges posed by different individual use scenarios. Hence, the regulatory requirements are best regarded as an essential minimum level of safety; further improvement essential. Discussed here is a model for developing an explosive precursor safety system. With the Singapore legal requirements for an explosive precursor as the minimum, the Deming Cycle for continuous improvement was used to develop a fully mature safety program, across two Plan-Do-Check-Act cycles that incorporated feedback and observation of continuous practice.

By Hugo Schmidt

INTRODUCTION

In Singapore, the prospect of terrorism is of constant concern, with the official warning being 'Not if, but when'. As a consequence, the handling and storage of explosive precursors is tightly regulated. Under the Singapore Arms and Explosive Act, incorrect handling of explosive precursors is punishable by up to 2 years in jail.[1] Based in Singapore, the Cambridge Centre for Advanced Research and Education in Singapore (Cambridge CARES) uses several chemicals listed as explosive precursors by the Singapore government.

Cambridge CARES initially acquired the relevant licenses to store and possess explosive precursors at the beginning of its laboratory's operational lifetime. As Cambridge CARES grew in size and matured in its research, it was found that in addition to the legal standard required for licensing, further opportunities for improvements in safety and awareness of responsibility were needed.

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The Deming Cycle[2,3] (Figure 1) is an established tool for continuous improvement. As the initial licensing followed the classic cycle of Plan, Do, Check, Act, the Deming Cycle was used for further improvement in explosive precursor safety. Here the process is described as an example of good practice for the control of explosive precursors, and of the practical use of the Deming Cycle in laboratory safety.

FIRST DEMING CYCLE

There are 15 explosive precursors requiring licenses to possess and use under Singapore law (see Table 1). The aim of the first Deming Cycle was to establish procedures of explosive precursor safety that were in line with regulatory requirements, and so to obtain the necessary licenses for the operation of Cambridge CARES laboratory.

Pre-existing Laboratory Security

Access to the Cambridge CARES laboratories is already controlled. The laboratories are located on the 7th story of the CREATE Research Tower. Access to the tower and the laboratories is controlled by electronic key cards that need to be issued to a named individual who has previously been approved of by CARES. Allowing third parties to access the laboratory without the knowledge and consent of the laboratory manager is grounds for disciplinary action. In addition, the entrances of the laboratories and the Research Tower are monitored by CCTV by CREATE's security staff.

First Plan Phase — Determining Laboratory and Legal Requirements

Planning began by asking Cambridge CARES research which listed explosive precursors they would likely use, and at what quantities. Having obtained this information, CARES consulted the relevant authorities to determine the specific requirements for licenses to possess and control, and to store explosive precursors. These were:

1. A designated lockable storage cabinet for the explosive precursors
2. A CCTV camera with 24 hour surveillance of the storage cabinets, a minimum rate of 12 frames per second, and with the footage stored continuously for 30 days.
3. Security procedures regulating access to the explosive precursors, including a stock control system, and specification that all users of the precursors be trained in their safe usage, and how to response to emergencies or security breaches such as theft.
4. A list of all directors, shareholders and other persons listed in the Accounting and Corporate

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Regulatory Authority (ACRA) registration of Cambridge CARES, along with dates of birth, countries of birth, genders, and nationalities.

First Do Phase — Constructing Safety System

A suitable fixed cabinet was selected as the Explosive Precursor cabinet. Keys to the cabinet were placed in the sole possession of the laboratory manager. This stage necessitated revision of previous requirements: while initial requests were for two cabinets for two different sub-sections of the laboratory, this was found to be unfeasible.

Two sets of logging systems were created: a withdrawals book located in the explosive precursor cabinet, in which all withdrawals were to be listed with volumes used, and a log of all purchases (consisting of purchase orders and delivery notes) located in the Cambridge CARES offices.

CCTV cameras were selected on the basis of ease-of-use and cost-effectiveness. After comparing quotations, it was decided to use the FOSCAM FI982 camera. FOSCAM cameras work by "plug and play" – connected to Ethernet, they are accessible from any computer on the system, though password protected.

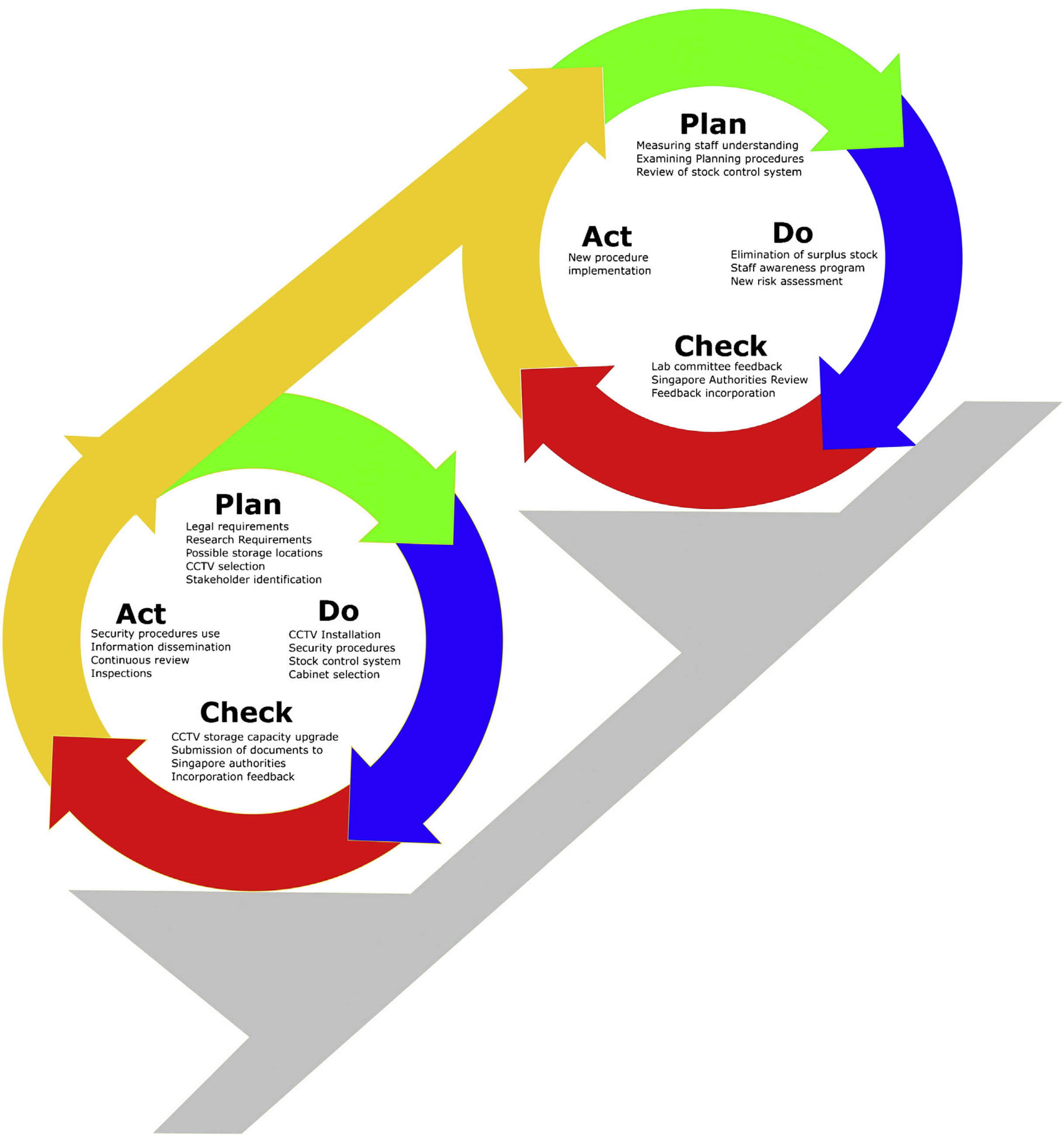

Figure 1. Deming Cycle as applied to explosive precursor safety in Singapore.

Table 1. Explosive Precursors Requiring Licenses under Singapore Law.[4]

		Exclusions
1	Ammonium nitrate	a. Aqueous solutions containing less than 60% weight in weight of ammonium nitrate. b. Any material in solid form comprising a mixture of components, one of which is ammonium nitrate, where the nitrogen content derived from ammonium nitrate is less than 28% by weight of the said mixture.
2	Ammonium perchlorate	–
3	Barium nitrate	Preparations and solutions containing less than 10%, weight in weight, of barium nitrate.
4	Guanidine nitrate	–
5	Hydrogen peroxide	Preparations and solutions containing not more than 20%, weight in weight, of hydrogen peroxide.
6	Potassium chlorate	–
7	Potassium nitrate	Preparations and solutions containing less than 5%, weight in weight, of potassium nitrate or a combination of both potassium nitrate and sodium nitrate.
8	Potassium nitrite	Aqueous solutions containing less than 5% weight in weight, of potassium nitrite.
9	Potassium perchlorate	–
10	Sodium chlorate	–
11	Sodium nitrate	Preparations and solutions containing less than 5%, weight in weight, of sodium nitrate or a combination of both sodium nitrate and potassium nitrate.
12	Sodium nitrite	Aqueous solutions containing less than 5%, weight in weight, of sodium nitrite.
13	Sodium perchlorate	–
14	Perchloric acid	–
15	Tetranitromethane	–

The first FOSCAM camera was installed on a nearby table and trained on the designated explosive precursor cabinet. Connection was established from the laboratory manager's computer which was located in the main office building, separate from the laboratory.

In addition, two further FOSCAM cameras were installed in both laboratories, observing the doors. These were set to motion detection recording, taking 30 s recordings whenever someone enters or leaves the laboratories. These created an additional level of safety as well as allowing CARES to ensure that the rules on never working alone outside of hours are observed.

Security procedures were produced fulfilling all requirements detailed by the Singapore government. In particular, the procedures outlined the stocktaking and recording of all activities involving explosive precursors, and the appointment of individual responsible persons who are permitted access to the explosive precursor cabinet.

First Check Phase — Internal Review and Examination by Singapore Authorities

Reviewing the CCTV set up, it was found that it was not possible to store the necessary 30 days of continuous recording on the laboratory manager's computer. To allow the recording to take place, a further NVR client recorder was purchased along with a 2 terabyte hard disk. Located in a separate building to the research laboratories, tampering with the recordings is extremely difficult.

After completion of the initial safety set-up, a Letter of Declaration was submitted. This included a detailed description of the security procedures pertaining to explosive precursors, and was submitted alongside plans showing the location of the explosive precursor cabinet, and screenshots of the CCTV footage observing the cabinet.

Feedback stated was that while most things were in order, the CCTV camera's location was unsuitable. Located on a laboratory bench, it left open the possibility of tampering. In response to this, the camera was relocated to a ceiling-girder, out of reach without a ladder, and connected to the Ethernet via an extended cable secured to the wall with cable wall clips (see Figure 2). The new set up was photographed and the changes resubmitted. Following this, the facility was judged sufficiently secure, and the Explosive Precursor licenses granted.

First Act Phase — Implementation of Safety Procedures

The security procedures were incorporated into Cambridge CARES safety culture in several ways. CCTV footage is reviewed weekly by the CARES laboratory manager to verify that no system failure had occurred. The

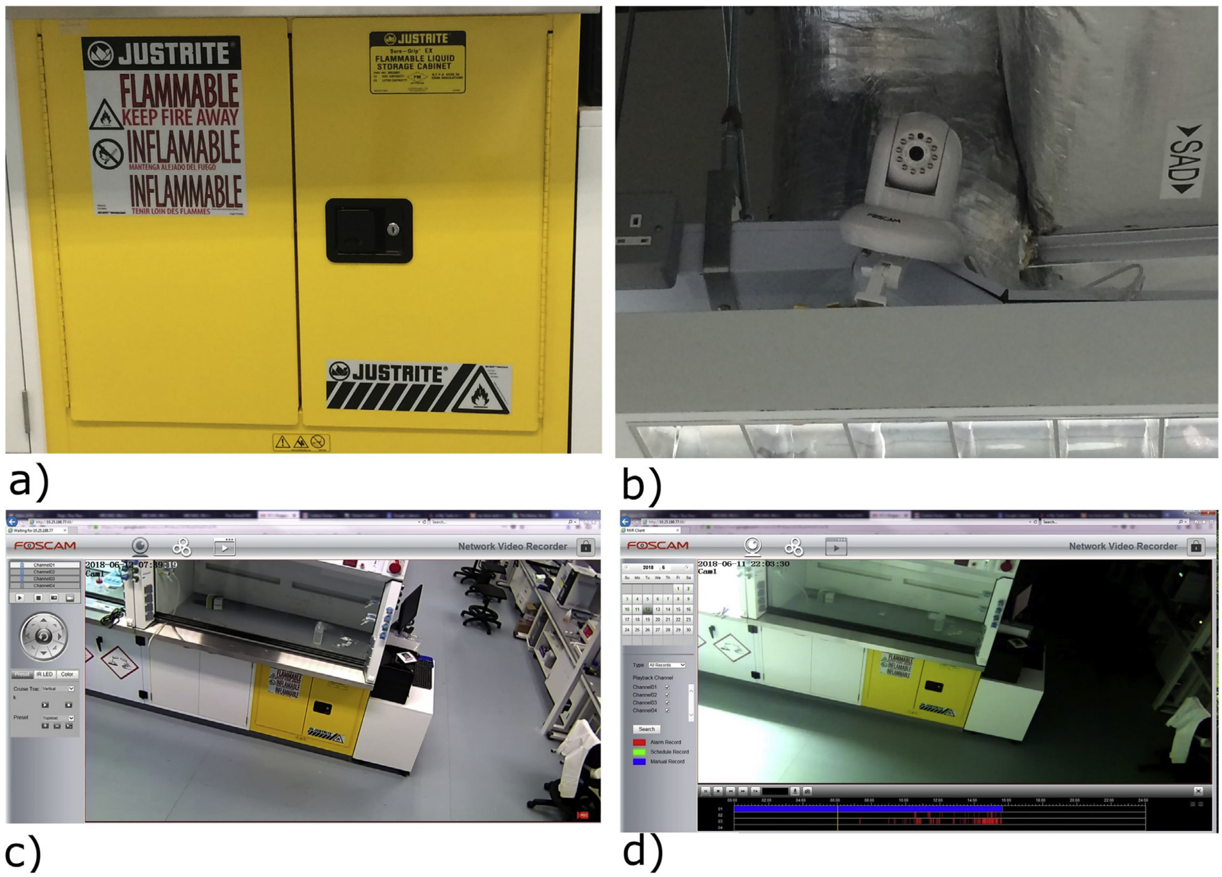

Figure 2. (a) Explosive precursor safety cabinet, (b) CCTV camera location, (c) screencap showing the observation of the explosive precursor cabinet, (d) screencap showing the night-vision ability of the explosive precursor cabinet.

explosive precursor security procedures were published to all research staff via the internal Dropbox system; all CARES staff were briefed on the procedures. The Singapore legislation on the use of explosive precursors was incorporated into the CARES induction procedure. In addition to the CARES laboratory manager, a single responsible person was duly appointed, and issued with the only spare key to the safety cabinet. Orders and deliveries were monitored for any purchases of explosive precursors (purchases of explosive precursors in Singapore require submission of the relevant licenses, so monitoring of orders and deliveries represented a secondary safety measure).

During the next 24 months of the licenses being held, the CARES premises were subject to random inspections by Singapore authorities and no cause for complaint or correction were found.

SECOND DEMING CYCLE

Background to Second Deming Cycle

In the 18 months since the first Deming Cycle had been completed and the licenses on Explosive Precursors had been obtained, some events suggested opportunities for further systematic improvement of the safety procedures:

- Laboratory members forgetting or being unaware of which chemicals are listed explosive precursors.
- The separation between the use-log and the stock-log made tracking cumbersome.
- Standard hazardous material risk assessments were limited in the detail they provided on the use of explosive precursors (e.g., the chemical intermediaries produced etc.).
- International research workers at CARES being unaware that chemicals that could be easily bought in other countries are tightly controlled in Singapore. For example, sodium nitrate is a controlled explosive precursor in Singapore but is freely available for purchase on Amazon.[5]
- Due to staff turnover, certain explosive precursors were no longer necessary, and stock remained unused in the cabinet.

Though none of these instances led to a failure of the safety procedures, they did show room for improvement. As the date of license renewal was approaching (31st July 2018), this seemed an opportunity exceed the basic legal requirements of explosive precursor safety. This seemed particularly advisable, given the increased climate of terrorism awareness in Singapore, following the failed terror attack on Marina Bay Sands by Batam militants.[6]

Second Plan Phase — Determining Opportunities for Improvement

Reviewing the incidents of the last 18 months, it was found that they revealed four opportunities for improvement, namely:

- Communication and knowledge – increasing the awareness of all CARES staff of what chemicals are listed as explosive precursors in Singapore law.
- Planning – planning the use of explosive precursors could extend beyond the general purpose of use, to detailing the specific steps and intermediaries created in any experiments conducted.
- Record keeping – a single system of records, even a divided one, has the potential for accidental loss etc. A redundant system of record keeping, especially in different forms, would provide a greater security.
- Stock Control – Adoption of ALARA – As Low As Reasonably Achievable – standards with respect to Explosive Precursor stocks.[7] Research laboratories tend to accumulate chemical stocks; this understandable given that research progress cannot be completely predicted and sometimes only trace amounts of chemicals are necessary. However, in the case of a legally regulated chemicals with security implications, a periodic elimination of unneeded chemicals is prudent.

With these principles identified, further improvement was initiated.

Second Do Phase — Creating Improved Systems

Stock control was improved through revision of the procedures on stock maintenance. Any explosive precursor that had gone unused for three months is subject to review. If no laboratory users claimed the chemical and explained plans for its use, it is to be marked for elimination.

Knowledge of the explosive precursors regulated by the Singapore government was spread by placing informative posters through the laboratories, in locations where they are hard to avoid – on exit doors, on chemical cabinets etc. To incentivize laboratory workers to take note of these, the posters stress that knowledge of what licenses are required to purchase needed chemical will minimize delays in conducting experiments. Furthermore, notes on the explosive precursor regulations of Singapore are circulated regularly via the weekly email maintained by the laboratory manager.

Planning was improved by creating a new explosive precursor risk assessment to be filled in before any use. CARES hazardous materials risk assessment still applies to all chemicals in use, including explosive precursors, the new risk assessment required detailing the full experimental procedure each explosive precursors was to be used in and all intermediaries produced. The new risk assessment also acts to improve knowledge of regulated explosive precursors, as it begins with a full statement of the relevant Singapore legislation on explosive precursors, as well as a full list of the chemicals that qualify.

Improvements in record keeping were implemented by creating a five tier system of inspection and record keeping:

1. A withdrawal log kept with the explosive precursors, detailing the date of any withdrawals, the name and signature of the withdrawer, the amounts withdrawn from the cabinet, and the purpose of each withdrawal.
2. A secondary log of all explosive precursor stocks kept separately in the laboratory manager's office, detailing the running total stock of all explosive precursors, and any the reason for any changes (name of withdrawer, purpose etc.) The secondary log is updated weekly, or in accordance with any change.
3. The contents of the safety cabinet are reviewed daily, with all changes noted, and entered into the records.
4. Once a week, the contents of the safety cabinet and the withdrawal log are photographed. The photographs are time-stamped and stored electronically by emailing them to a designated email account used solely for this purpose. Copies are also kept in dated folders on the laboratory manager's computer.
5. Copies of all purchase orders and delivery notes are kept in the laboratory manager's office in a designated folder.

Second Check Phase — Feedback from the Lab Committee and the Singapore Authorities

After drafting the planned changes, the laboratory manager discussed the specifics of each step with the laboratory committee, the representatives of the lab workers at CARES. This allowed them to give their feedback (e.g., review of the draft Explosive Precursor Risk Assessment etc.). The new system met with approval.

As the time of license renewal approached, there was the opportunity to obtain feedback and buy-in from the Singapore authorities. The procedure was approved, though CARES was advised that it would be better to have a printed form for all withdrawals, rather than the handwritten log that had previously been used. In response, such a printed form was incorporated.

Second Act Phase — Implementation of the New Procedures

As of June 2018, the new safety procedures have been implemented and are so far successful. Simple modifications (such as the daily inspection of the explosive precursor cabinet) require a negligible time-investment and lead to considerably greater awareness and security of the site. All laboratory users making use of explosive precursors have taken to the new system.

FUTURE CYCLES

The Deming Cycle is a tool of continuous improvement. Further improvement cycles will be implemented in the future, as time permits. Some further challenges to be addressed are:

- Secure storage of temperature sensitive materials. Hydrogen peroxide needs to be stored at 4 °C to prevent its decomposition. If Cambridge CARES needs to purchase hydrogen peroxide, it will be necessary to establish a secure and suitable refrigeration unit.

- Segregation of incompatible controlled chemicals. Chemical segregation was not a concern for CARES, as only a small number of chemicals were purchased. If larger numbers of explosive precursors need to be purchased, it will be necessary to establish further secure and segregated cabinets.
- Electronic security of CCTV records. At the moment, CARES has no formal procedure for the development of passwords. Passwords are changed from factory settings and include letters, numbers and special characters, but formal procedures may lend to greater security. Similarly, it may be useful to test the security of the Ethernet system, currently the responsibility of CREATE.

CONCLUSIONS — THE VALUE OF GOING ABOVE-AND-BEYOND

Adherence to the bare minimum of safety required by legislation is never enough. General legislations, regardless of whether they are at the institution or the national level, will never be completely fitted to the unique challenges of individual research laboratories. 'Going above and beyond' such requirements is the only effective way in which laboratory safety can be addressed. Furthermore, such improvements in one area of safety often lead to improvements in other areas (e.g., the installation of multiple cameras allowed CARES to enforce its rules on never working alone outside of hours).

The Deming Cycle provides a proven method for such continuous improvement. The Plan-Do-Check-Act approach allows a structured process of improvement that is well suited to the laboratory environment – for example, getting buy-in from the laboratory committee during the "Plan" phase not only helped improve safety procedures, but established commitment to those procedures once implemented. Here it is shown how this general model can be used to create a mature safety program with the regulatory requirements as a solid baseline.

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