IDENTIFYING UNIVERSITY CHEMICALS THAT POSE SECURITY RISKS: A SIMPLE QUALITATIVE APPROACH

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ABSTRACT

Various laboratory-focused tools and methodologies for completing a safety risk assessment have been published, yet few similar resources to address chemical security exist. Herein we describe a chemical security risk assessment case study at a university in a developing country. In this case study, we demonstrate a chemical security risk assessment for a university chemistry department, using an original inventory of 645 entries which was condensed to 295 chemicals after removing duplicates and erroneous entries. We then prioritized to highlight 83 chemicals of interest based on hazardous or dual-use properties that could lead to unacceptable consequences. We further refined to a list of 34 high-risk chemicals that required action, 48 chemicals that may need further justification and consideration for additional protection, and 1 chemical that did not need further consideration for additional protection.

KEYWORDS

Chemical security, risk assessment, nonproliferation, toxic, precursor, dual-use

1. INTRODUCTION

Chemical risk management utilizes a range of engineering controls, organizational management systems, and/or operational practices to manage the safety and security risks posed by chemicals. Chemical safety aims to prevent an accidental release of hazardous materials or energy, while chemical security is the protection, control, and accountability of chemicals. More specifically, chemical security deals with preventing a person or group of persons with motivation and capabilities to cause harm through the unauthorized access, loss, theft, misuse, diversion or *intentional* release of hazardous materials or energy. “Threat” is sometimes used interchangeably with “hazard”, but in this paper, “threat” is used synonymously with “adversary” and specifically refers to people with motivations and capabilities to cause harm. Stated more simply, chemical safety aims to protect people from chemicals while chemical security aims to protect chemicals from people (Figure 1**Error! Reference source not found.**).

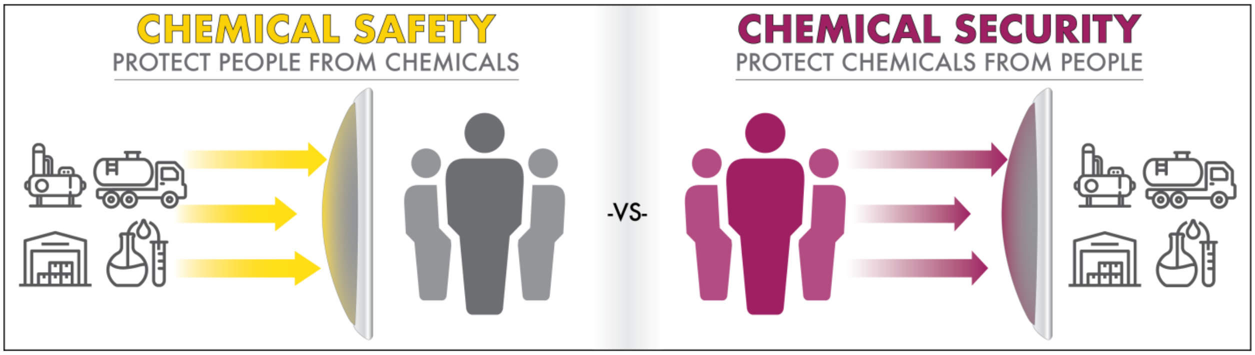

Figure 1. Visual depiction of chemical safety and chemical security.

Resources for controlling safety and security risks at most institutions are limited.[1] Thus, it is important to systematically prioritize risks so that resources are used most effectively when improving or adding new controls. In general, a risk assessment is a structured process that 1) identifies assets, hazards, threats, and controls for a laboratory and/or facility; 2) evaluates the likelihood and consequences of an unwanted event, as well as vulnerabilities to such an event by assessing the effectiveness of existing controls designed to eliminate, prevent, reduce, or mitigate a hazardous or threatening scenario; and 3) identifies and prioritizes risk mitigations.

Various laboratory-focused tools and methodologies for completing a safety risk assessment have been published, yet few similar resources to address chemical security exist.[1] Several security risk-related research papers for chemical plants and the process industry are available,[2-9] but as the US Chemical Safety Board has noted, industrial guidelines and approaches do not always lend themselves to be directly applied to academic institutions.[10] This paper presents a simple qualitative security risk assessment approach that has been applied at a university in a developing country. The approach follows one described in the Sandia National Laboratories Chemical Security Handbook: Security Risk Assessment for Laboratories.[11] The qualitative approach identified several low-cost, low-effort security improvements that the university could adopt. While the process of assessing safety and security risks is similar, the corresponding hazards, threats, and controls are different enough that security focused examples, like the one presented in this paper, help illustrate the differences for audiences that have not conducted a security risk assessment before.

1.1 University Overview

The University is a public institution focused on teaching, though some professors have research programs. Almost all chemicals used at the university belong to and are stored in the Chemistry Department in a single Chemical Storage Room located on the second floor of the Science Building. The Chemistry Department has 3 professors, 15 lecturers, 7 technicians, 350 undergraduate students majoring in chemistry, and 10 PhD students. The Chemistry Department also teaches introductory chemistry to approximately 1,000 students from other departments (e.g., engineering, biology, and biochemistry). Some specialty chemicals are used by the PhD students within the department, but the majority chemical use is by professors, lecturers, technicians, and students during required general, organic, inorganic, or analytical chemistry laboratories. Chemicals are kept in the Chemical Storage Room, unless (1) being used in the preparation room for future research experiments, or (2) being used in undergraduate laboratory exercises.

The Chemistry Department has received several grants from foreign governments to upgrade security systems within the Science Building, including video surveillance closed-circuit television (CCTV) that records activities but is not monitored by a guard in real-time, and a biometric thumbprint entry system for the Chemical Storage Room. In order to open the Chemical Storage Room, an individual must have both a physical key and access granted through the thumbprint scanner; only the Head Laboratory Technician and Chairman of the Chemistry Department have a physical key to the Chemical Storage Room. When staff needs chemicals, the Chairman or Head Technician escort individuals into the room.

All of the ~12,000 students live off campus and both students and staff must present a photo identification badge to enter the campus. While vehicles are manually searched upon entry and exit, bags and backpacks are not.

All chemicals in the department were being stored with the same level of security and the Chairman wanted to know which, if any, of the chemicals warranted additional protections. Therefore, a chemical security risk assessment was conducted.

2. CHEMICAL SECURITY RISK ASSESSMENT

At the most basic level, security risk assessments are multi-step, iterative processes that scale to the level of risk being addressed to answer the following questions,

- What do we have?

- Who would want it?
- Should we be concerned?
- Is this acceptable?
- What do we do about it?

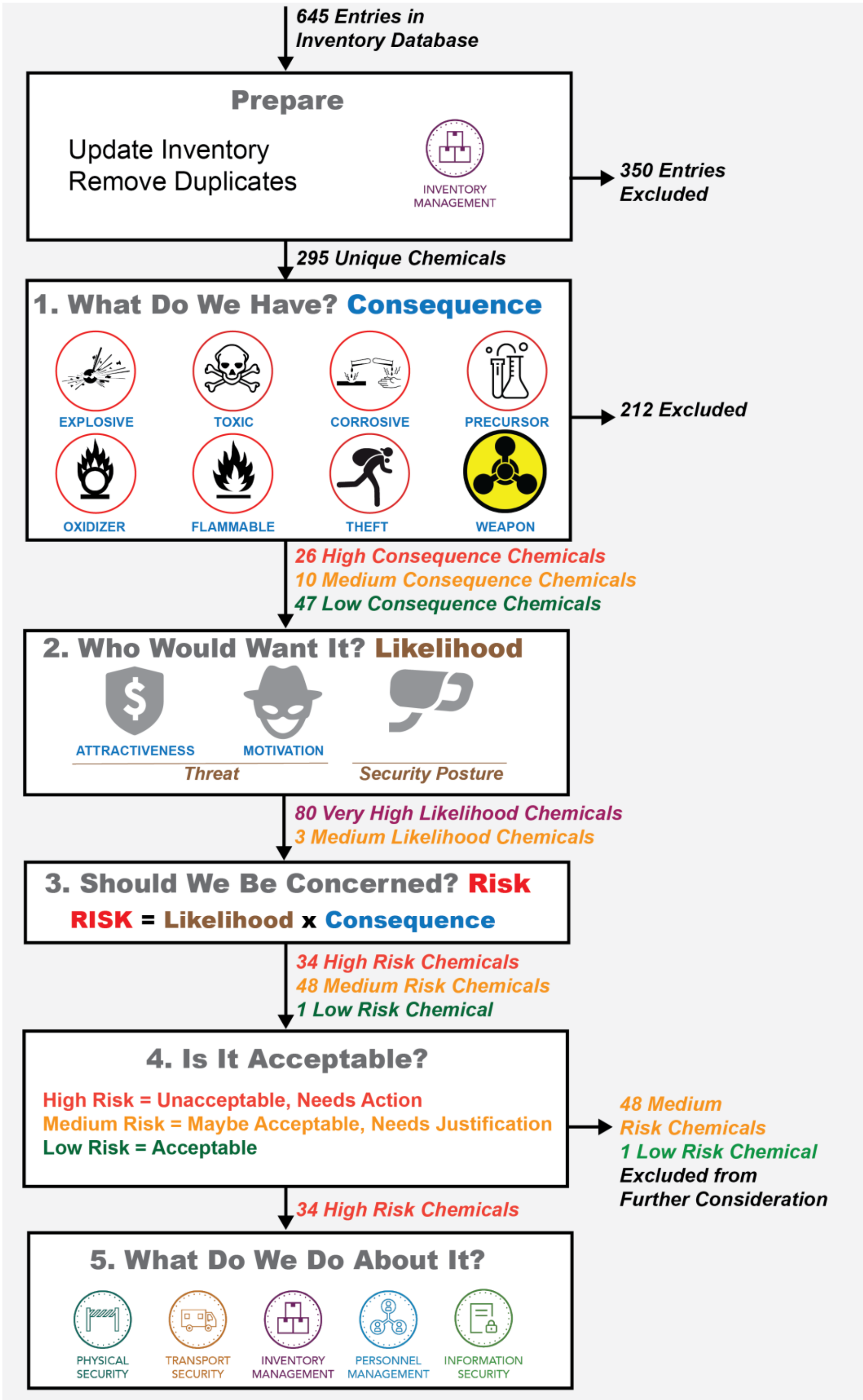

Figure 2. Flowchart of Laboratory Chemical Security Risk Assessment.

The first step in the process is to screen which chemicals and equipment pose the greatest security risks so that resources can be focused on them (**Figure 2**). Prioritization should take the perspectives of both the laboratory and potential adversaries into account. For a laboratory, valuable chemicals and equipment might be defined by costs or as those which, if stolen, could cause significant delays in research activities. These attributes are different than what an adversary with an intent to cause harm might consider valuable, such as,

1. Highly toxic chemicals that are easily dispersed.
2. Flammable chemicals.
3. Chemicals that can be used as an explosive, or as a precursor to an explosive.
4. Corrosive and/or oxidizer chemicals.
5. Chemicals that have been used as a chemical weapon previously or are precursors to a chemical weapon.
6. Equipment with dual-use applications, meaning can it be misapplied to manufacture illicit drugs, explosives, or chemical weapons that pose a threat to public health and safety, agricultural crops, the environment, or national security.

For the case study described in this paper, the risk team, which comprised the authors of this paper and university staff that answered questions about the chemical inventory, focused its efforts on chemicals and did not assess equipment. The Globally Harmonized System (GHS) classifications listed in **Error! Reference source not found.** were used to identify chemicals that are highly explosive, flammable, toxic, corrosive, or oxidizing.[12] Explosive and chemical weapon precursors do not necessarily fall into one of the categories listed in Table 1, so the authors also consulted internationally published lists that identify chemical weapon agents and their precursors; explosives and their precursors; and dual-use chemical manufacturing equipment (Table 2).

Table 1. GHS codes that identify explosive, flammable, toxic, and corrosive hazards used to screen chemicals for the risk assessment described in this paper. Category 1 hazards were considered for each hazard, except H300 where both Category 1 and 2 hazards were assessed.

Codes	Hazard

H200, H201, H202, H203	Explosive
H220, H221, H224, H260	Flammable
H300 (category 1 and 2), H310 H330	toxicity (ingestion, dermal, inhalation)
H314, H318	Corrosive
H270, H271	Oxidizing

Table 2. Internationally published lists to identify high-security risk chemical assets.

Organization	Name & Description of List
The Organisation for the Prohibition of Chemical Weapons (OPCW) [13]	The Chemical Weapons Convention (CWC) identifies and categorizes toxic chemicals and their precursors according to the following conditions: *Schedule 1* chemicals have been or could easily be used as chemical weapons and have very limited uses for peaceful purposes. *Schedule 2* chemicals include precursors to chemical weapons or chemicals that can be used as chemical weapons. *Schedule 3* chemicals include chemicals that are widely used for peaceful purposes but could also be used to produce chemical weapons.
The Australia Group (AG) [14]	AG published its *Common Control Lists* which includes a list of dual-use chemicals, equipment, technology and software.
The European Union (EU) [15]	The EU published *Council Regulation (EC) No 428/*2009 which includes a list of dual-use items.
The Department of the Homeland Security (DHS) of the United States [16]	The *Chemical Facility Anti-Terrorism Standards (CFATS) Chemical of Interest (COI) List* includes security concerns for chemicals on the list, such as, toxic releases, flammable releases, explosives, theft to produce a weapon of mass effect, and sabotaged or contamination concerns.

A chemical's attractiveness for theft is not universal, and local variables need to also be considered. For instance, local criminal activities or illicit drug production can make some chemicals more attractive for theft than others. In some countries, criminals are interested in procuring chloroform ($CHCl_3$) so they can incapacitate people during kidnapping attempts. While in the United States, precursor chemicals and equipment have been stolen from a university setting to synthesize methamphetamine.[17]

For the University, the decision was made to prioritize chemicals in its inventory that:

1. appeared in one of the lists identified in Table 2;
2. had GHS acute toxicity, skin corrosion, flammable, explosive, or corrosive hazard codes and categories listed Table 1; note, GHS codes were obtained from multiple sources; [18-22]
3. had a history of being stolen from the university, which included ethanol and mercury; and,

4. was known to be attractive to local criminals, in particular chloroform. Note, chloroform appears on the US DHS CFATS COI list;[16] however, for this analysis we review chloroform under its classification of being a chemical that is locally known to be stolen frequently.

Three years prior, the University implemented a computer-based chemical inventory management system (CIMS) developed by Sandia National Laboratories called CMS©.[23] Technicians recorded 645 chemical entries into the CIMS database, but upon review for this risk assessment it was discovered that the information was incomplete, and some chemical names were misspelled or in local languages. Since CAS numbers were not being recorded for all chemicals, names were being used to count entries. This led to overcounting the total number of chemicals when multiple names were used to describe the same chemical, for instance soda lime, sodalime, sodaline, lime were all used for Soda lime, CAS Number 8006-28-8. Before moving forward with the chemical prioritization, an effort was made to correct and harmonize chemical names and update the CAS number for each entry using the PubChem database and SigmaAldrich websites to find CAS Numbers.[21, 22]

Ultimately, it was determined that the Chemistry Department only had 295 unique chemicals.

2.1 Consequence Ranking

The quantities of chemical assessed were lab-scale, meaning they were stored in containers that could fit into a backpack or pocket. The team did not try and quantify the number of people who might be injured or the severity of an injury. The team acknowledges that if larger quantities were brought onsite that more sophisticated quantitate approaches might be needed. The following qualitative consequence table was developed to rank the consequence scenarios as low, medium, or high (Table 3). Factors that affected the team’s ranking included:

- The ability to remove a chemical from someone’s skin before it could do harm (e.g. a solid may be brushed off whereas a liquid would require washing with solvents).
- Severity of an injury in response to an attack (death versus injury).
- Quantity of chemical.
- Historical thefts of a chemical.
- Known use of the chemical to cause harm (e.g. chemical weapon or explosive precursor).

With the exception of chemical weapon and explosive precursors, the team considered the ease of using the chemical to injure a fellow student or faculty member as is, meaning no further processing (i.e. grinding a solid to a finer powder). Also, the team recognized the local use of chloroform to subdue victims during kidnappings, a history of mercury theft for the artisanal gold industry, and a history of ethanol theft for consumption; historically, perpetrators have been found with stolen chemicals while attempted to exit university grounds or were found intoxicated.

Table 3. Consequence scenarios that could result in one or more injuries either on- or off-site due to the release of hazardous materials or energy.

Consequence Scenario Descriptions	Ranking	Risk Assessment Team Rationale	Total Number of Chemicals Matching this Description
GHS Category 1 “fatal in contact with skin” chemicals or GHS Category 1 or 2 “fatal if swallowed” chemicals could be released near a person or poured into a drink or food. **Theft of any amount of chemical weapon or explosive precursors as identified from the list in Table 2.**	High	The lethal dose of these chemicals may be less than 3.5 grams, approximately the volume of a sugar packet. The university does not want any of its chemicals to be used to produce explosives or known chemical weapons.	26 of 295

Flammable materials (volumes greater than a backpack quantity) could be poured on a person and ignited. **Corrosive liquids.** **Chemicals used by local criminals or chemicals that have a history of being stolen.**	Medium	The university at this time does not purchase large drums or quantities of solvents or other flammable material, but if that changes, we assume the increased volume could lead to lethal injuries or more individuals being affected at one time. Liquid corrosives (e.g. acids) would be difficult to remove before injury occurs. Theft of chemicals like mercury and ethanol have a financial affect that the university would like to prevent. Also, the university does not want any of its chemicals to support local criminal activity, so loss of chloroform will be added to this category.	10 of 269* *269 = (295–26 high risk chemicals)
Flammable materials (volume less than a backpack quantity) could be poured on or thrown at a person and ignited. **Corrosive solids could be thrown at someone.** **Oxidizers could be used to create a fire**	Low	The team assumes the amount of material that could be thrown on a person (1 L or less) would be small enough that the number of people affected would be small and injuries would be lower and non-lethal. Corrosive solids can be brushed off of the body, minimizing potential injury. The university does not want any of its chemicals to be used in the production of improvised explosives as this could damage the university's reputation.	47 of 259* *259 = (295 - 26 high risk–10 medium risk chemicals)

or an explosion.			

Eighty three of those chemicals have either the GHS codes listed in Table 1 or appear in the lists given in Table 2. More specifically, twenty-four of those chemicals appeared on one of the lists from Table 2. The University did not have the resources to procure additional secure chemical cabinets for all 83 chemicals, so efforts were made to further prioritize chemicals with security concerns by developing attractiveness matrices.

2.2 Asset Attractiveness ranking

Asset attractiveness rankings (Table 4) considered the ease of procurement and cost of a chemical. A chemical that is readily available offsite will be less attractive than one that is either expensive or otherwise difficult to obtain.

Table 4: Asset Attractiveness Ranking

Asset Attractiveness Ranking	Ranking
Readily available offsite.	Low Attractive (LA)
Readily available offsite, but costly.	Medium Attractive (MA)
Difficult to obtain offsite either because quantity, availability, or regulatory controls. Chemical weapon precursors are difficult to find in the country and require special import licenses.	High Attractive (HA)

Threat Characterization ranking

The team next discussed the threat profile in the country. As chemists, the team generally felt they did not have the knowledge to provide detailed descriptions on the intent, motivations, capabilities, or interests of specific threat groups. The team plans to consult with the university security team and local law enforcement in the future. All of the team members were well-aware of the general threat profile of the region and decided to rank these threats from their perspectives. The team discussed that there is a high level of crime in the country, and although the majority of crimes have not involved chemicals the group felt chemicals could be targeted in the future. The group constructed a matrix generally describing the threat groups to assess which classes of chemicals each threat might target (Table 5).

Discussions focused on the fact there are non-violent, opportunistic thefts primarily for the purposes of financial gain. The perpetrators of such acts may include students, financially-stressed employees, and given the university's urban setting, there is the potential for intruders unaffiliated with the university to steal items of value given the right opportunity. The team felt that opportunistic threats may steal indiscriminately as they would have little understanding of the value or use of most chemicals. There are also numerous organized thefts throughout the region, but these are generally non-violent. Such organized, motivated thefts may steal chemicals that will be sold for financial gain (e.g. mercury), illicit drug production, or used maliciously (e.g., chloroform). There are also documented cases of attacks by foreign violent extremist organizations—these groups may be interested in chemical weapon precursors, highly toxic compounds, or chemicals that could be used to make explosives. The team concluded that theft was the major concern for the university as there were not large quantities of chemicals on site that could pose serious release or sabotage concerns.

Table 5: Threat Characterization Ranking

Threat Characterization	Ranking	Team Description
Opportunistic, non-violent.	O	Individuals who might steal chemicals indiscriminately for financial purposes if the opportunity presents (e.g., students)
Motivated, but non-violent. Has the means and capabilities to plan a theft and wait for the opportune time.	MN	Organized, motivated individuals who want chemicals for financial and other malicious purposes (illicit drugs, kidnappings, etc.) but unlikely to use violence to steal these chemicals.
Motivated and violent. Has the means and capabilities to plan an attack and wait for the opportune time.	MV	Motivated, violent groups that may target chemicals that can be used for violent attacks, such as acid attacks, bombings, fatal poisonings, or chemical weapon attacks.

2.3 Security Posture

Next the team discussed the security posture of the laboratory by identifying the engineering controls, organizational management systems, and operational practices related to the security of chemicals. The team started by drawing a map of the university campus, the science building, and the layout of the Chemical Storage Room. First, they considered known engineering controls such as gates, guard stations, roadways, doors, CCTVs, and chemical storage boxes (Figure 3). They also discussed university policies and practices that might affect the efficacy of these controls, to include inventory recording and reporting requirements, policies for students and faculty to access chemicals, and CCTV monitoring practices.

Throughout the discussion on security posture, the team placed controls for chemicals into the categories of “deterrence,” “detection,” “delay,” and “response” (Table 6).[11] In this context, deterrence refers to security measures that might discourage someone from stealing a chemical (*e.g.*, fences). Detection refers to measures that can identify that someone has stolen or is attempting to steal a chemical (*e.g.*, security guards, alarm systems). Delay refers to measures that can slow an adversary down to provide time for security guards or law enforcement to arrive on scene (*e.g.*, tire puncture devices). Response refers to guards or law enforcement intervention in the theft (this may occur onsite or offsite for thefts).

Table 6: Security Measures at the University

Security Measures	Examples at the University	Additional Thoughts
Deterrence	Perimeter fence, CCTV, doors, access control policies, photo ID badges,	CCTV was not added to detection, because they are not monitored in real time. As such, they do not provide any alarms and serve primarily as a deterrence.
Detection	Campus security guard, inventory system	The inventory system can help identify if chemicals have gone missing. While backpacks and bags are not searched, cars leaving the campus are.
Delay	Gate	The university has no delay features for pedestrians, but if threats traveled by car and were detected by the campus security guard, the campus gate could be closed to slow exit from the campus
Response	Campus security guard, local law enforcement	We note that CCTV is not a true response measures and unlikely to help prevent an active theft. However, given that CCTV systems record 24/7, video footage can be accessed to help identify and apprehend thieves after an incident

There are several key takeaways from this conversation for the risk assessment. All chemicals in the Chemical Storage Room had the same level of security and therefore could be ranked the same with the same level of security posture. Some deterrence security measures are in place, such as security guards at the entrance of the university, locked doors, and strict access control policies to the Chemical Storage Room. However, the team noted that there are no alarm or detection systems in place that could notify security guard or law enforcement to respond to the Science Building. There are no delay methods for pedestrian threats, which the team felt would be the most likely threat given the ease of walking off the campus with a backpack and not being searched. Although there are some response measures, such as the campus security guards, they are not stationed near or within the Science Building. Virtually no detection or response measures are in place for the Chemical Building. Thus, the chemical security posture was deemed to have notable security gaps that allow opportunity for adversaries to successfully steal chemicals from the university.

The team then developed a table that pairs asset attractiveness and threat characterization so that likelihood of theft could be qualitatively assigned to each chemical (Table 7). Since all chemicals are located in the same room currently and therefore have the same security posture, there is only one column for security posture in this table. In the future, if chemicals are moved or if additional security measures are added, additional columns could be added with different likelihood rankings.

Table 7: Exemplar likelihood matrix.

		Security Posture
		Notable security gaps allow opportunity for adversary to be successful; virtually no detection or response.
Attractiveness & Threat Pairs	MV + HA	Very High
	MN + HA	Very High
	O + HA	High
	MV + MA	Very High
	MN + MA	High
	O + MA	Medium
	MV + LA	Medium
	MN + LA	Medium
	O + LA	Low

2.4 Further Chemical Prioritization

Next, the team created a risk table (Table 8) that combined the qualitative likelihood assignments from Table 7 with the consequence scenarios in Table 3. For example, the 26 high-security chemical assets identified from lists given in Table 2 were assigned a consequence raking of High (H), the attractiveness was ranked as high because these chemicals are difficult to obtain (HA), and the highest threat, motivated-violent, was assumed.

These variables lead to a risk ranking of Very-High•High (VH•H) in Table 8. In contrast, the 44 solid chemicals with a GHS health hazard code of H314 or H318 are assigned a consequence ranking of Low (L), the attractiveness was ranked as medium because these chemicals cannot be readily purchased (MA), and the highest threat, motivated-violent, was still assumed. These variables lead to a risk ranking of Very-High•Low (VH•L) in Table 8. A summary of the final rankings is provided in (Table 9).

Table 8: Exemplar Risk Table for Consequence and Likelihood. The green, yellow, and red colors are discussed in the text.

		Consequences		
		Low	Medium	High
Likelihood	Very High	VH•L	VH•M	VH•H
	High	H•L	H•M	H•H
	Medium	M•L	M•M	M•H
	Low	L•L	L•M	L•H

Table 9: Final Risk Rankings of Chemicals

Chemical Hazard Group **(# of chemicals)**	Consequence Ranking	Attractivene ss	Threat	Security Posture	Likelihood Ranking	Risk Pairing	Final Risk
Chemical of Concern List **(24)**	High	HA	MV	Notable Gaps	Very High	VH•H	High
GHS Category 2 Acute Dermal Toxicity **(2)**	High	HA	MV	Notable Gaps	Very High	VH•H	High
GHS Corrosive Liquids H314/H318 **(7)**	Medium	MA	MV	Notable Gaps	Very High	VH•M	High
Chemicals w/ History of Theft **(3)**	Medium	CCl_3—HA	CCl_3—MV	Notable Gaps	CCl_3—Very High	CCl_3— VH•M	CCl_3—High
		Hg—MA	Hg—O		Hg—Medium	Hg—M•M	Hg—Medium
		EtOH—MA	EtOH—O		EtOH—Medium	EtOH—M•M	EtOH—Medium
GHS Corrosive Solids H314/H318 **(44)**	Low	MA	MV	Notable Gaps	Very High	VH•L	Medium
GHS Oxidizers H271 **(2)**	Low	MA	MV	Notable Gaps	Very High	VH•L	Medium
GHS Flammable material H260 **(1)**	Low	LA	MV	Notable Gaps	Medium	M•L	Low

3. RISK ACCEPTABILITY

After identifying the risk categories for the prioritized chemicals, the team discussed risk acceptability. In general, the team was concerned about risks that had the highest likelihood and consequences. When reviewing Table 8, the team decided to color-code the risk categories in Table 8 as red (needs action), yellow (maybe acceptable, need to justify actions or lack thereof), and green (acceptable).

Based on Table 9, there are 34 high-security chemicals that required action. The team agreed that they cannot change the inherent hazards of the chemical, but they could adjust the quantity of the chemical on site. This led to a discussion on hazard elimination, where one of the team members asked, "*do we even need the high-risk chemicals? Is there a reason to keep the CWC precursors on hand*?" The team decided to explore disposing the CWC precursors; however, it is difficult to dispose of chemical waste properly because of limited waste management resources in the county. For now, the team will look to protect the chemicals onsite and/or identify other local universities that have an active need for the chemicals *and* can secure them.

Since all chemicals are currently stored with the same level of security, the team next addressed security vulnerabilities. The team structured conversations on improving the University's deterrence, detection, delay, and response that went beyond alarms, locks and guards to include personnel management, material control and accountability, information security, transportation security, and physical security.

Personnel management

Ultimately, personnel management is a means to prevent an insider theft where people affiliated with or employed by the University are the threats of concern.

- Suggestions to perform criminal background checks on individuals were rejected. Instead, team members suggested there are two ways to assess reliability of potential hires: (1) practical exam for technicians to demonstrate they understand chemical hazards and how to respect chemicals and (2) in-person interviews to assess their character.
- The team discussed that color-coded badges to readily identify authorized users because it is a recommended security measure.[24] It was determined that the number of authorized chemical uses is small (10>) and they all know each other very well so badges were deemed excessive.
- The team suggested that a new policy could be implemented that requires a meeting with employees that are quitting or retiring or being fired, during which the individual returns all keys and badges.

Material Control and Accountability

Material Control and Accountability (MC&A) includes the control and accountability of chemicals, information, and equipment at an institution.

- The team discussed that the quantities are known every year when chemicals are purchased, but that it is unlikely that the technicians will update the quantity of chemical within each bottle after each use. It was suggested that an inventory audit be performed at a pre-determined schedule (i.e. twice a year) to identify if either entire bottles, or significant quantities, of chemicals are missing.
- The team thought it would be very important to update chemical owner as some chemicals stored in Chemical Storage Room are owned by other departments. Additionally, it was mentioned that representatives from other departments should be involved in the inventory process at least once per year.

Information Security

Sensitive information which could assist an adversary gain access to chemicals for malicious purposes needs to be protected to both deter and delay threats.

- The CMS© system already password protects the inventory. The only people with access to the inventory are the chairman, the head technician, and some staff members who have varying levels of access.
- The computer on which the CMS© system is stored is password protected.
- It was recommended that the passwords to CMS© and computer be updated regularly.

Transportation Security

- There is no chemical transportation between buildings at the university.
- The only chemical transport is within the Sciences Building or within the Chemistry Department from the Chemical Storage Room to the Chemical Preparation Room and the Chemical Preparation Room to the Laboratories.
- The team decided it would be beneficial for both safety and security purposes to develop a policy that chemicals can only be transported during times when there are limited numbers of students in the hallways (i.e., not immediately before classes start or immediately after the finish).

Physical Security

- **Strengths**. The university already has many security deterrence measures. One of the team members noted that the CCTVs have discouraged students from misbehaving in the building and they have the added benefit of preventing cheating on exams.
- **Realistic approaches**. The team suggested a short study to determine how often people are using the higher risk chemicals would inform appropriate mitigation measures. If high risk chemicals are rarely used, they could be locked away or possibly given to other local universities with an active need and ability to protect. If the chemicals are used frequently, then the team would need to identify an approach that protects the chemicals but is not so onerous that workflow issues motivate workers to, for example, prop open a door.[25]
- **Increase overall chemical storage security**. All chemicals should be protected in a room with intrusion alarms, due to the asset attractiveness and threat reasoning above. If financial resources are available to install an alarm system, the alarm could sound at the guard station near entrance to the university. Lastly, the team discussed the possibility of stationing a guard outside the Chemistry Department during non-business hours. This was discussed as a possible quick solution, but not necessarily a sustainable solution as labor for guards can be quite expensive over time.
- **Increase focused security.** For higher risk chemicals, more layers of protection should be included. For example, there could be a locking chemical and flammables cabinet placed in the Chemical Storage Room to hold high-security risk chemicals. Or the room could be partitioned by a new wall to add an additional layer of protection for higher risk chemicals. Note, the risk assessment team documented that chemicals should only be stored together if they have compatible storage requirements. Other safety considerations also need to be addressed, for example chemicals that may release flammable or toxic vapors should stored in appropriately vented cabinets. The team plans to consult TRGS-510 for a systematic approach compatible chemical storage.[26] To add an additional delay feature, locking chemical cabinets or partitioned room could have a different key than the key required for the Chemical Storage Room.

4. FINAL RECOMMENDATIONS

Based on the risk assessment, the team noticed that the principle factor increasing the risk of chemicals is the lack of an alarm *(detection)* to notify campus security guards of security breaches. The team recommends the installation of an alarm at the entrance for the Chemical Storage Room (Figure 4). The team also recommends that the delay time for the high-security chemicals be increased by adding an additional layer of physical security in the form of a locking cabinet or room partition within the Storage Room. Along with these changes, the team recommends moving the CCTV to the inside of the Chemical Storage Room, so that if an alarm is sounded, security guards may assess if someone is attempting to break into the higher-risk chemical storage area.

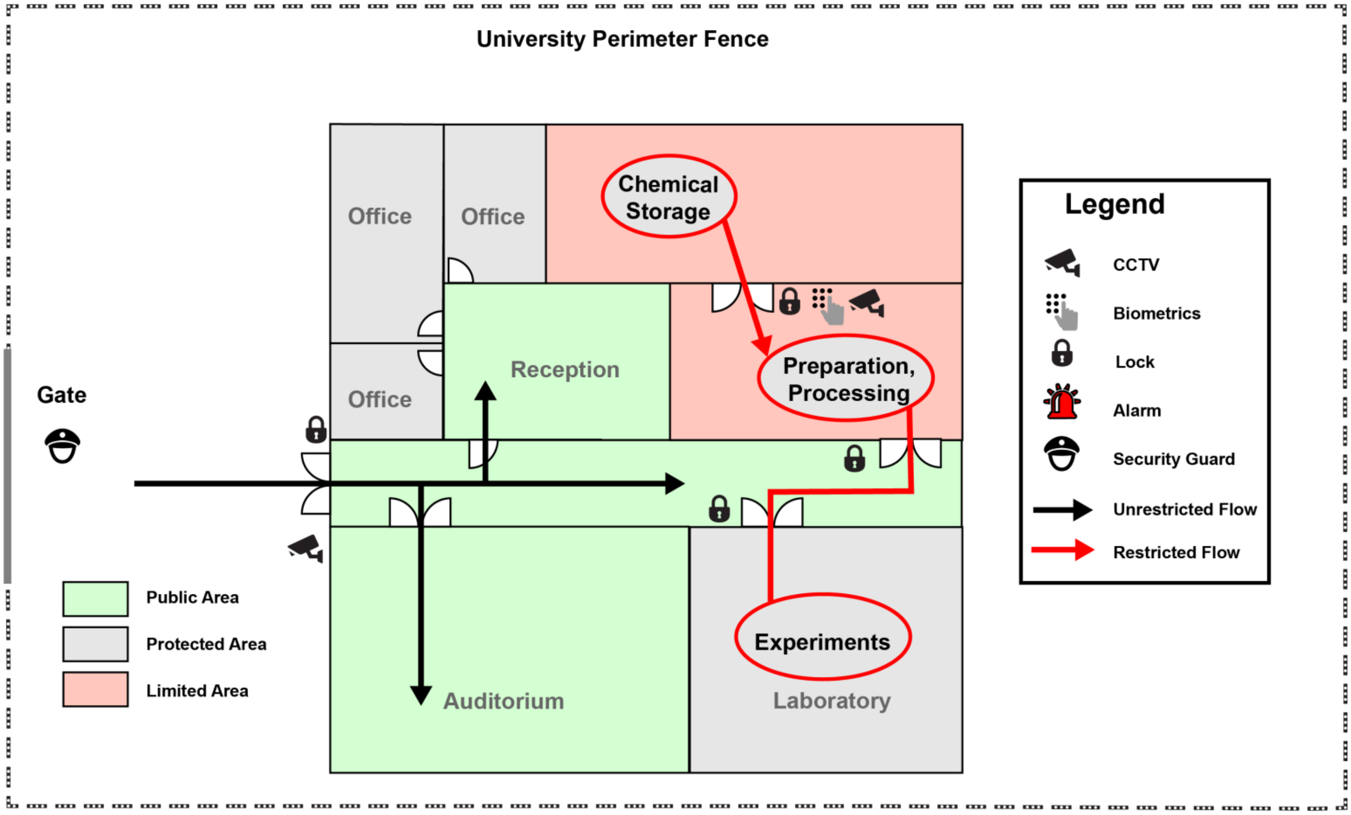

Figure 3: Map of the Science Building and existing security features at the time of the security risk assessment.

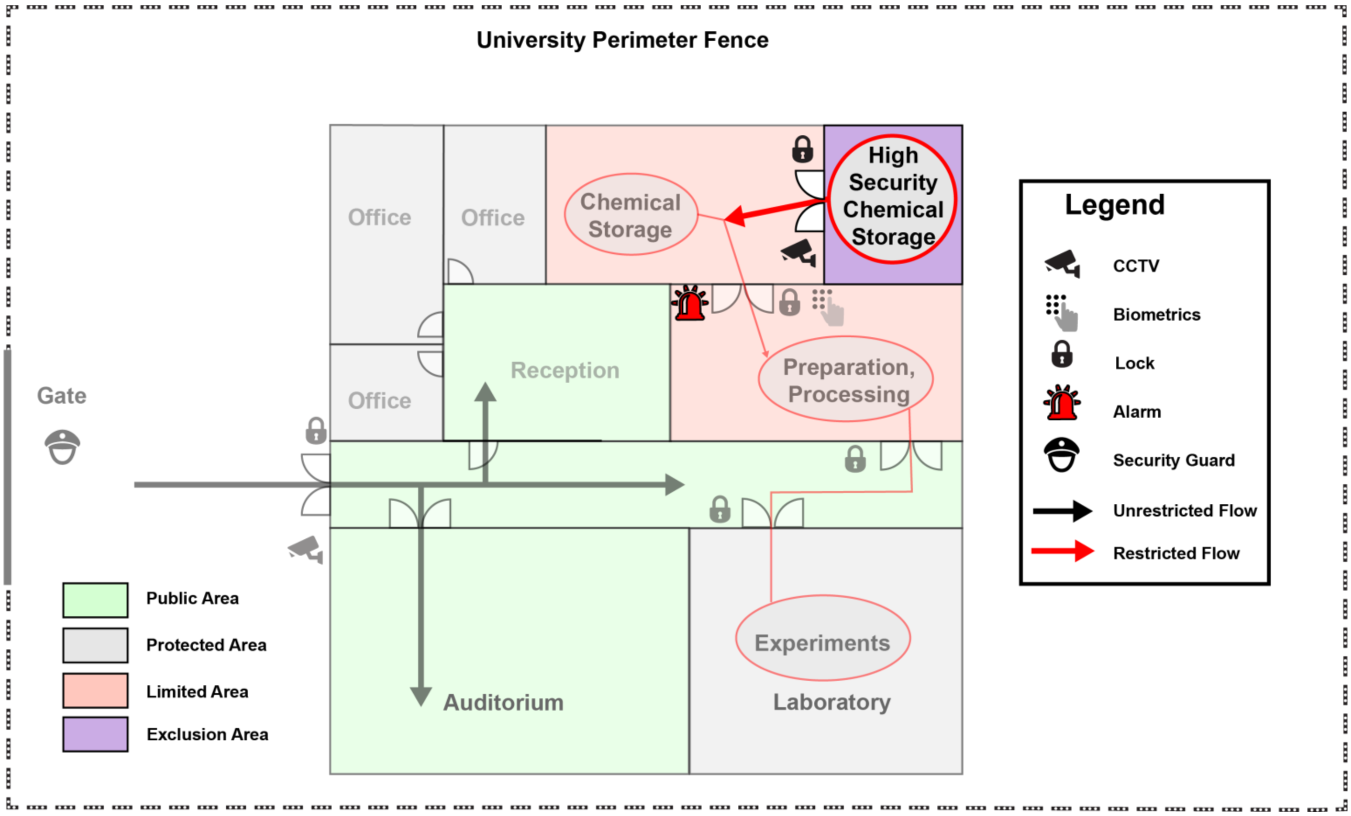

Figure 4: Map of Science Building and *proposed* security features. Recommendations include: (1) partition of Chemical Storage Room to add a chemical security storage room that has more access control restrictions, (2) addition of an alarm system at the entrance of the chemical store room that can notify security guards of unauthorized entry, and (3) placement of CCTV inside chemical store room to determine if any alarms are due to security breaches or false alarms.

5. CONCLUSIONS

Chemical security risk assessment is a systematic process that helps inform the assessors of the relative consequences of malicious uses of chemicals, equipment, and information. An assessment will also help identify and develop a plan to reduce an institution's key vulnerabilities. Risk reduction measures will vary from institution to institution, and will be based on each institution's overall assets, resources, and risk tolerance.

In this case study, we demonstrated a chemical security risk assessment for a university chemistry department. The team originally started with inventory of 645 entries, which was condensed to 295 unique chemical entries by removing duplicates and erroneous entries. The 295 chemicals were then prioritized to highlight 83 chemicals of interest based on hazardous or dual-use properties that could lead to unacceptable consequences. Eighty-three chemicals were deemed too many to secure given the resources of the university. Therefore, further prioritization occurred by considering factors that could increase the likelihood of their theft or misuse, including asset attractiveness, threat profiling, and the university security posture. This further refinement resulted in a list of 34 high-risk chemicals that required action, 48 chemicals that may need further justification and consideration for additional protection, and 1 chemical that did not need further consideration for additional protection. The analysis highlighted that adding an alarm to the entry of the Chemical Storage Room would increase the detection of an attempted theft and an additional layer of physical protection for high risk materials would both deter and delay attempts to steal chemicals; delaying an attempt to steal chemicals, increases the likelihood an attempt would be detected and stopped.

Risk assessments should be used as a tool to inform and communicate decisions about risks by considering the cost, benefits, and feasibility associated with risk mitigation. A risk assessment will help an institution to determine if risks arising from chemical assets or processes are acceptable, or if action is needed to mitigate the risks. Chemical laboratories can never eliminate risks completely; however, they can be managed.

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REFERENCES AND ADDITIONAL NOTES

1. Nelson, A. W.; Hotchkiss, P. J., Introducing the Journal of Chemical Education’s Special Issue on Chemical Security. *Journal of Chemical Education* **2020,** *97* (7), 1698-1701.
2. Landucci, G.; Argenti, F.; Cozzani, V.; Reniers, G., Assessment of attack likelihood to support security risk assessment studies for chemical facilities. *Process Safety and Environmental Protection* **2017,** *110*, 102-114.
3. Santos, C.; El Zahran, T.; Weiland, J.; Anwar, M.; Schier, J., Characterizing chemical terrorism incidents collected by the global terrorism database, 1970-2015. *Prehospital and disaster medicine* **2019,** *34* (4), 385-392.
4. Lee, Y.; Kim, J.; Kim, J.; Kim, J.; Moon, I., Development of a risk assessment program for chemical terrorism. *Korean Journal of Chemical Engineering* **2010,** *27* (2), 399-408.
5. Moore, D. A.; Fuller, B.; Hazzan, M.; Jones, J. W., Development of a security vulnerability assessment process for the RAMCAP chemical sector. *Journal of hazardous materials* **2007,** *142* (3), 689-694.
6. Egorov, A.; Savitskaya, T., Methods and models for the risk analysis and security management of chemical plants. *Theoretical foundations of chemical engineering* **2010,** *44* (3), 326-338.
7. Zhu, R.; Hu, X.; Li, X.; Ye, H.; Jia, N., Modeling and risk analysis of chemical terrorist attacks: A bayesian network method. *Int J Environ Res Public Health* **2020,** *17* (6), 2051.
8. Khakzad, N.; Martinez, I. S.; Kwon, H. M.; Stewart, C.; Perera, R.; Reniers, G., Security risk assessment and management in chemical plants: Challenges and new trends. *Process Safety Progress* **2018,** *37* (2), 211-220.

9. Bajpai, S.; Sachdeva, A.; Gupta, J., Security risk assessment: Applying the concepts of fuzzy logic. *Journal of Hazardous Materials* **2010,** *173* (1-3), 258-264.
10. U.S. Chemical Safety and Hazard Investigation Board. [No. 2010-05-I-TX]. *Texas Tech University Laboratory Explosion*. 2011.
11. Nelson, A. W.; Mulcahy, M. *Chemical Security Handbook: Security Risk Assessment for Laboratories*; SAND2020-6033; Other: 686801 United States 10.2172/1635333 Other: 686801 SNL English; ; Sandia National Lab. (SNL-NM), Albuquerque, NM (United States): 2020; p Medium: ED; Size: 70 p.
12. *Globally Harmonized System of Classification and Labelling of Chemicals (GHS)* United Nations: 2019.
13. Organisation for the Prohibition of Chemical Weapons https://www.opcw.org/ (accessed 8 July 2021).
14. Group, T. A. Export Control List: Chemical Weapons Precursors. https://www.dfat.gov.au/publications/minisite/theaustraliagroupnet/site/en/precursors.html.
15. Council Regulation (EC) No 428/2009. Union, T. E., Ed. Official Journal of the European Union, 2009.
16. U. S. Department of Homeland Security. *Chemical Facility Anti-Terrorism Standards, Appendix A: Chemicals of Interest (COI)*. 2009.
17. Kemsley, J., Student Accused Of Making Meth Agrees To Plea Deal. *Chemical & Engineering News* 2008.
18. Duke University, *Particularly Hazardous Substances, GHS Lookup Tool*. https://www.safety.duke.edu/sites/default/files/GHS_Lookup.xlsm (last accessed October 1, 2021)
19. Information on Chemicals. https://echa.europa.eu/information-on-chemicals (accessed 8 July 2020).
20. Fisher Scientific. https://www.fishersci.com/us/en/brands/I8T3NQD9/fisher-chemical.html (accessed 8 July 2020).
21. *Sigma Aldrich*. https://www.sigmaaldrich.com/united-states.html (accessed 8 July 2020).
22. PubChem. https://pubchem.ncbi.nlm.nih.gov/ (accessed 8 July 2020).
23. Payne, M. K.; Nelson, A. W.; Humphrey, W. R.; Straut, C. M., The Chemical Management System (CMS): A Useful Tool for Inventory Management. *Journal of Chemical Education* **2020** (7), 1795-1798.
24. Salerno, R. M.; Gaudioso, J.; Brodsky, B. H.; *Laboratory Biosecurity Handbook*, 1st ed.; CRC Press: Florida, 2007; p. 46.
25. Stuart, R.; Sweet, E.; Labosky, M.; Box, M.; Mulcahy, M. B., Safe Lab Design: A Call for Papers. *ACS Chemical Health & Safety* **2021,** *28* (3), 144-147.
26. German Federal Institute for Occupational Safety and Health, *Technische Regeln für Gefahrstoffe, (Technical Rules for Hazardous Substances) TRGS 510*. https://www.baua.de/EN/Service/Legislative-texts-and-technical-rules/Rules/TRGS/TRGS-510.html (last accessed October 1, 2021).