The staff and students in the National University of Singapore (NUS) are exposed to various hazards arising from its research and/or teaching activities. To ensure these hazards are addressed, NUS has established a comprehensive safety and health management system (SHMS). As part of this system, Principal Investigators (PIs) & Laboratory Supervisors are required to establish a safety and health management system (SHMS) for areas under their charge. They are required to identify the safety and health risks prior to the start of their research and teaching activities, and to implement the necessary mitigation measures. Their SHMS are subjected to regular certification audits. As of 2015, over 600 PIs have been certified to the scheme. This paper details the drivers behind the scheme & processes and, roles of key stakeholders in implementing the scheme. It also describes the benefits and limitations of the scheme.

**Keywords:** safety and health management system, certification audit, surveillance audit

1. Introduction

The National University of Singapore (NUS) is a research-intensive university which is highly ranked in three laboratory-based disciplines (i.e. 4th in engineering & technology, 17th in life sciences & medicine, 9th in natural sciences) assessed by four performance indicators, namely academic reputation, employer reputation, citations per paper, and H-index citations.1)

In 2014, NUS was awarded external grants of 631 million Singapore dollars for its research programmes.2) In NUS, laboratory-based research activities are conducted in 9 faculties/schools3) and 12 research institutes/centres4). The range of research topics is very diverse - ageing, biomedical science, translational medicine, material science, maritime, etc. These research activities encompass a wide range of hazards, including but are not limited to, biological agents that could result in laboratory-acquired infections, hazardous substances that could be harmful to humans if inhaled or ingested and flammable or reactive chemicals that could cause fire or explosion. NUS therefore decided in 2006 that it would need to develop a robust and comprehensive scheme to manage laboratory safety and health. NUS thus introduced a laboratory safety and health management system (SHMS) standard and a scheme to have PIs certified to this standard. The scheme was integrated into the NUS SHMS (Fig. 1). As of 2015, over 600 PIs (Table 1) have been certified to the scheme.

There were also reasons for implementing such a scheme. These are, such as (1) Research was getting more complex with collaboration among researchers, giving rise to new hazards. In 2014, more than 350 research collaborative agreements were signed.5) There was therefore a need to have a unified approach to managing safety, so as to facilitate collaboration among researchers. (2) Regulations were also another driver. Prior to 2006, PIs submitted risk assessments at a project level for review and approval by the safety office (hereafter referred to as "Office of Safety, Health and Environment (OSHE)") before the funds for their research grants can be released to them to embark on their research activities. In 2006, the Ministry of Manpower, Singapore enacted the Workplace Safety and Health Act. This act and its subsidiary regulation (Workplace Safety and Health (Risk Management) Regulations) required laboratories in Singapore to conduct risk assessments at the activity level instead of the project level.

The aforementioned reasons, which is the increasing volume and diversity of research activities, coupled with local legal requirements acted as the main drivers to have a more robust system to manage laboratory safety and health. NUS thus introduced a laboratory safety and health management system (SHMS) standard and a scheme to have PIs certified to this standard. The scheme was integrated into the NUS SHMS (Fig. 1). As of 2015, over 600 PIs (Table 1) have been certified to the scheme.

![Fig. 1](image_url) The NUS safety and health management system (SHMS) framework. A standard is provided to laboratory-based PIs to establish and implement their SHMS at the laboratory level.
2. Development of laboratory safety and health management system certification scheme

2.1 Overview of the standard

When staff at OSHE began developing the standard, they reviewed existing management system standards related to safety and health. International and local standards were referenced when developing the NUS laboratory SHMS standard (British Standards⁶) and Singapore Standards⁷. It was decided that the standard would adopt a framework with the elements of goal setting, planning, operational controls and performance measurement (Fig. 2).

This would require the PI to firstly identify (1) relevant safety and health policies, directives and manuals applicable to conducting his research in compliance to NUS or other institution that is hosting his research activities. (2) hazards and risks arising from his activities. The PI would do this through a process of conducting risk assessment for all his activities. This is termed as the “Plan” phase, as it helps the PI in determining the controls to manage his hazards and risks and make appropriate plans for their implementation.

Next stage is the “do” stage. Here, risk controls established in the “plan” stage are implemented. The PI is required to define roles and allocate responsibilities for implementing these controls and ensure personnel under his supervision are adequately trained and there is adequate communication of these controls to all affected stakeholders. Subsequently, the “check” stage is to measure and monitor the effectiveness of the risk controls. The “check” stage would include elements such as incident investigation and inspections. In the laboratory SHMS, the last stage “act” is where an internal management review of laboratory safety and health management system is conducted to determine areas of improvement.⁸ The results obtained in the “check” and “act” stage need to be evaluated and incorporated into the “plan” stage, thus making the laboratory SHMS a process of continual improvement.

2.2 Implementation of the SHMS

There are online trainings material prepared by OSHE to educate the PIs on the implementation and maintenance of the SHMS. The sequence for implementing the SHMS is as follows: Firstly, OSHE staff gives a briefing of the SHMS to the PI. The PI then has six months to implement the SHMS before the certification audit. An online SHMS training “Safety and Health Management System (SHMS)” has been developed by OSHE that details the processes required to establish the SHMS. The PIs, their staff and students can view this online training at their own convenience (Table 2). Next the PI and his team members start to develop their laboratory SHMS. The contents of the SHMS would be populated into standard templates that were designed by OSHE. The populated templates are then consolidated into an application package which is submitted to OSHE for review. OSHE staff will arrange with the PI to do a certification audit of their SHMS.

![Image of PDCA model for SHMS](image-url)

Table 1 The Number of PIs that have undergone the certification and surveillance from 2011 to 2015

<table>
<thead>
<tr>
<th>Year</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of PIs undergone certification audits</td>
<td>343</td>
<td>41</td>
<td>33</td>
<td>48</td>
<td>31</td>
</tr>
<tr>
<td>No. of PIs undergone surveillance audits</td>
<td>142</td>
<td>232</td>
<td>160</td>
<td>115</td>
<td>173</td>
</tr>
<tr>
<td>Total No. of PIs certified</td>
<td>655</td>
<td>645</td>
<td>657</td>
<td>673</td>
<td>655</td>
</tr>
<tr>
<td>Total No. of PIs</td>
<td>658</td>
<td>670</td>
<td>658</td>
<td>680</td>
<td>664</td>
</tr>
</tbody>
</table>

Fig. 2 The Plan-Do-Check-Act (PDCA) model for safety and health management system (SHMS) standard for laboratories.
2.3 Certification process

On the day of certification audit, the PI will share about his research activities and introduce his research team and key members of his team with safety responsibilities. OSHE staff will then review the documents, conduct interviews and visit the laboratory facilities to verify the extent that the SHMS has been implemented. At the end of the audit, there will be a closing meeting where OSHE staff will summarize the preliminary findings of the audit to the PI. The findings would be classified into the following categories: (i) areas for improvement (AFI) i.e. laboratory practices that would need improvement, (ii) category A (CAT A) findings (i.e. absence of implementation of any of the SHMS element), (iii) category B (CAT B) findings (i.e. non-compliance with safety and health related legal requirements or mandatory NUS requirements), and (iv) positive (i.e. good practices which are over and beyond what is expected of NUS standards). An audit report will be issued to the PI by OSHE staff. For the PI without any CAT A or CAT B findings, the PI will be issued the laboratory SHMS certificate. For the PI with CAT A or CAT B findings, he will be given one month to report the necessary corrective actions. OSHE staff will then do the necessary verification of the corrective actions and if the corrective actions proposed are adequate, the PI will be issued the laboratory SHMS certificate. The PI is then subjected to periodic (triennial or earlier) surveillance audits thereafter.

3. Benefits and limitations of the certification scheme

It is noted that the percentage of PIs with CAT A findings had decreased year on year, however the percentage of CAT B and AFI is noted to have increased from 2013 to 2015 (Fig. 3). It is also noted that there is an increase in the number of PIs who do not have CAT A findings as they progressed from their initial certification to their periodic surveillance audits (Fig. 4). This shows that through each audit cycle, they are progressively building up on their safety and health management system. The increase in the number of CAT B and AFI findings is due to changing regulations and NUS standards, which requires PIs time to implement them.

Table 2  Titles of the training modules PIs, staff and students are required to undertake in developing their laboratory SHMS

<table>
<thead>
<tr>
<th>Module</th>
<th>Module Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module 1</td>
<td>Introduction</td>
</tr>
<tr>
<td>Module 2</td>
<td>Elements of a Safety &amp; Health Management System</td>
</tr>
<tr>
<td>Module 3</td>
<td>Risk Assessment Methodology</td>
</tr>
<tr>
<td>Module 4</td>
<td>Introduction to Legal Requirements</td>
</tr>
<tr>
<td>Module 5</td>
<td>Roadmap to Certification</td>
</tr>
<tr>
<td>Module 6</td>
<td>Maintenance of Certification</td>
</tr>
</tbody>
</table>

Fig. 3 The percentage of PIs with audit findings in the years 2011–2015 (Note: The percentages of CAT A, CAT B and AFI findings do not add up to 100% as a PI may have findings in each category)

Fig. 4 The percentage of PIs with decreasing number of, with increasing number of, without, and with no changes in the number of, category A findings.

(A) Data for the initial certification audit and the subsequent surveillance audit.
(B) Data for the second and third audits.

While the scheme has brought many benefits to research laboratories, we have also noticed some limitations. Firstly as with any audit, the effectiveness of the audit process is dependent on the information provided by the PI to the auditors (OSHE staff). Some PIs may submit incomplete or insufficient information prior to the audit, which could result in OSHE staff (Auditors) spending more time understanding the PI’s SHMS. There is also feedback from PIs that the process is document intensive and manpower resources are required to keep the SHMS regularly updated. OSHE has therefore embarked on developing a number of online tools to facilitate the PI in managing the documentation required for maintaining the system.
4. Conclusion

In conclusion, the NUS laboratory SHMS standard has provided PIs an effective means to manage the hazards and risks arising from their laboratory activities in a holistic and comprehensive manner. NUS has successfully developed its own SHMS standard and has required all its PIs to undergo a certification process to this standard. The reduction in CAT A findings from the certification to the surveillance audit indicates that the SHMS is effective in driving continual improvement, particularly after the third audit, the reduction in CAT A findings is most significant.

References

3) Faculty of Dentistry, School of Design and Environment, Duke-NUS Medical School, Faculty of Engineering, Yong Loo Lin School of Medicine, Saw Swee Hock School of Public Health, Faculty of Science, Yale-NUS College, and Faculty of Arts and Social Sciences.
4) Centre for Quantum Technologies, Cancer Science Institute of Singapore, Temasek Laboratories, Mechanobiology Institute, Life Sciences Institute, Singapore Synchrotron Light Source, NUS Environmental Research Institute, NUS Nanoscience and Nanotechnology Initiative, Tropical Marine Science Institute, Interactive & Digital Media Institute, Solar Energy Research Institute of Singapore, and Singapore Institute for Neurotechnology.
9) National University of Singapore: NUS Procedures for the Management of the Laboratory Safety & Health Management System, revision 03.